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THE EFFECTS OF THREE DIMENSIONAL MODELING ON LABOR
PRODUCTIVITY THROUGH ENHANCING VISUALIZATION OF CRAFT
WORKERS IN THE INDUSTRIAL CONSTRUCTION INDUSTRY

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The School of Human Resource Education
and Workforce Development

by

Gerrad Matthew Delatte
B.S., Louisiana State University, 1990
MBA, Louisiana State University, 1998
December 2014

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This work is dedicated to my wife, Kim, and our two daughters, Meagan and Macy.
Girls, may your educational endeavors provide the key to open the door to opportunity and
success.

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ABSTRACT

The primary purpose of this study was to determine if the use of three dimensional (3D) modeling to enhance visualization of structural steel installation would increase labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana.

The construction industry has seen a decline in labor productivity for many years. The effects of low labor productivity in the construction sector causes unnecessary escalated costs, scheduled completion dates to slip, and conflicts between the owner, engineering firm, and the construction company. The need for reversing this decline and improving construction productivity is critical. The loss of productivity has adverse consequences in the construction industry and modern society as a whole.

This study included 41 individuals who were industrial construction workers installing structural steel during the research period at a selected southeastern Louisiana chemical facility. The study utilized a one-group pretest-posttest time series design. The dependent variable was labor productivity measures and the independent variables were providing 3D modeling shots, age, gender, total years of construction experience, worker classification, and frequency of looking at the 3D modeling shots.

Using the paired t-test procedure, significant differences were found between labor productivity measures before and after introducing 3D modeling. Using multiple regression analysis, the researcher identified a statistically significant model. The variable frequency of looking at the 3D modeling shots explained 11.5% of the variance in mean labor productivity measures in the third week after introducing 3D modeling. This indicated that workers who reported that they looked at the 3D modeling shots more frequently tended to have higher labor productivity scores.

Based on these findings, the researcher concluded that the introduction of 3D modeling shots had a significant impact on labor productivity measures. The researcher recommends further research in other disciplines and construction sectors. In addition, future research should be conducted to determine if other mechanisms to convey the 3D modeling shots have a significant impact on labor productivity. Lastly, the researcher recommends that chief executive officers of construction organizations implement the use of 3D modeling during the construction phase to enable workers to visualize the installation process before it occurs.

CHAPTER 1: INTRODUCTION

Rationale

Human Effort

Throughout the world's history, there has always been a desire to build incredible monuments, castles, pyramids, buildings, and other great works of art. One key resource in mankind's achievements of creating and constructing has always been human effort. Over the course of history, this human effort or labor has either been voluntary or non-voluntary. Regardless, the human effort has always been measured in some form or fashion such as the number of workers needed to construct an object and a time frame. For example, the construction of ancient Egyptian pyramids took decades to create with thousands of workers. The need for individuals to produce at a high and efficient level has been a theme in the world's construction endeavors. In today's society, human effort is basically measured in the same way but with more sophisticated methods using computer software to calculate labor requirements and project schedule durations. It's imperative that the rate of producing or building an object with human effort or labor is measured and calculated so costs and schedules can be developed. Acceptable labor productivity is essential to compete in today's marketplace just as it was thousands of years ago.

Labor Productivity

The idea to be efficient and productive seems to be a natural tendency. However, many barriers prevent construction workers from achieving an optimum level of productivity. Some of these barriers include the number of work hours in a given week, specific jobsite conditions, weather, the number of change orders, coordination of work activities, visualizing the work environment and activities, and communication (Adrian, 2004). Having low productivity in the construction sector causes cost overruns, schedule extensions, and bad client relations between

the owner, engineering firm, and the construction firm. Construction labor productivity is difficult to calculate as a whole industry. The U.S. Bureau of Labor Statistics does not provide an overall construction productivity index due to many factors. Some of these factors include but are not limited to the construction industry being very fragmented, projects being unique in nature, and many small companies having limited reporting capabilities (Adrian, 2004). According to Teicholz (2004), the productivity of the construction industry has decreased over the past 40 years. The need for reversing this trend and improving construction productivity is critical. The loss of productivity has adverse consequences in the construction industry and modern society as a whole.

There is no single solution to improve construction productivity. Many techniques, methods, and programs have been utilized by various firms. Many firms realize that increasing work hours during the week lowers productivity. Fatigue is the major issue with extended work hours. The workers tend to become mentally and physically tired at the end of the week. Work hours greater than 40 hours in a given week decreases labor productivity (Adrian, 2004). The construction firm may institute programs to provide better communication and coordination among work crafts. However, visualization and spatial reasoning of the work environment and activities have not been adequately addressed up to this point.

Three Dimensional Modeling and Visualization

Most of the academic and industrial research on computer aided design (CAD) and visualization in construction has concentrated on design and pre-construction planning (Technion, S., Radosavljevic & Technion, B., 2010). There has been little field or jobsite related research conducted with CAD and visualization concerning construction productivity. Visualization of construction information is not only important during the design phase but it is

becoming increasingly important during the construction phase (Ganah, Bouchlaghem, Anumba, 2005). However, current research efforts do not focus on visualization using computer applications in the construction industry (Ganah et al., 2005). Many occupations including construction related fields rely on spatial ability and intelligence (Bannatyne, 2003).

The day to day use of three dimensional (3D) CAD or Building Information Modeling (BIM) has not been utilized in all construction sectors and to its fullest extent possible. Although BIM has been used primarily in the commercial construction industry, the industrial engineering and construction sector is beginning to employ a version of this technology. Civil, structural steel, piping, and mechanical equipment are being designed and engineered in a three dimensional CAD environment. The industrial construction industry can utilize this technology available from the owner and engineering firms to aid in the construction process.

By utilizing the 3D model, construction firms can produce a rendering of a completed project for use on the jobsite. Construction supervisors, foreman, and workers can use the model to visualize the installation of components and be made aware of any interference before actually performing the work. By utilizing the 3D model, the workers will be able to visualize the work process and have spatial reference points which would logically lead to installing the construction components faster and therefore increasing labor productivity.

Industrial Construction Research

This researcher has found limited labor productivity studies that provide empirical data concerning the use of 3D modeling to enhance visualization in the industrial construction sector. Many barriers to perform research in an industrial facility become paramount. The owner of the facility may not see a direct benefit of the research to the overall effort of building their specific construction project. Construction firms may not want to spend the resources to assist the

researcher and may not understand the research process in general. In addition, these firms may fear that confidential information concerning their employees and work processes will be disclosed to the general public. Perhaps researchers do not have the personal contacts to present research proposals to the facility owners and construction firms and therefore do not pursue these research opportunities.

There is a lack of research being performed in industrial construction related to labor productivity. This researcher has seen an increase in the use of 3D modeling by the owners and engineering firms. However, some projects do not maximize the capabilities of the 3D software. Even if a project uses 3D modeling software, the owner and /or engineering firm may not share the model with the construction firm due to fear of confidentiality issues with the engineering design information. From this researcher's experience, if the model is shared with the construction firm, only a "viewer" version of the software is provided. This version lacks the specific design information but indicates construction components and a depiction of the completed project which can be used for visualization purposes. The "viewer" version through software such as Autodesk Navisworks® lets the user navigate and explore the model. Using this software in research to provide visualization could provide a key to increase labor productivity. Research such as this aimed to discover new techniques in the industrial construction sector is needed and warranted.

Purpose of the Study

The primary purpose of this study was to determine if the use of three dimensional (3D) modeling to enhance visualization of structural steel installation would increase labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana.

Specific Objectives

There were six objectives of the study that were explored.

1. Describe industrial construction workers that were working on a project in a selected industrial facility in southeastern Louisiana on the following selected personal and professional demographic characteristics:

- i. age

- ii. gender

- iii. total years of construction experience

- iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc). This

classification was based on the number of years of experience in construction, how long the worker has been at other classification levels, and scores on standardized written craft examinations given by the company. Other criteria used in the evaluation included if the worker had formal craft training and certifications in programs such as those offered through the Associated Builders and Contractors or the National Center for Construction Education and Research (NCCER).

- v. frequency of looking at the three dimensional model shots

- vi. perceived helpfulness of the three dimensional model shots.

2. Determine the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana on three consecutive weekly measures taken before introducing three dimensional modeling. These labor productivity measures were the pretest scores.

Structural steel installation labor productivity was defined as:

Labor hours earned during structural steel installation divided by labor hours expended during structural steel installation;

Where:

Labor hours earned = estimated labor hours using company or industry standards x
installation percentage complete of the steel work items;

Labor hours expended = actual hours worked installing the steel work items.

3. Determine the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana on three consecutive weekly measures taken after introducing three dimensional modeling. These labor productivity measures were the posttest scores.
4. Compare the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana before introducing three dimensional modeling with each of the three consecutive weekly measures taken after introducing three dimensional modeling.
5. Determine if a model exists explaining a significant portion of the variance in the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana before introducing three dimensional modeling from the following selected personal and professional demographic characteristics:
 - i. age
 - ii. gender
 - iii. total years of construction experience
 - iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc).
6. Determine if a model exists explaining a significant portion of the variance in the structural steel installation labor productivity of industrial construction workers in a

selected industrial facility in southeastern Louisiana for each of the three weeks after introducing three dimensional modeling from the following selected personal and professional demographic characteristics:

- i. age
- ii. gender
- iii. total years of construction experience
- iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc)
- v. frequency of looking at the three dimensional model shots.

Significance of the Study

Construction labor productivity is a major concern for many owners, engineering firms, and construction organizations. Low labor productivity can increase construction costs and extend the schedule duration of a project.

There has been limited research on the possible effects of three dimensional modeling on industrial construction labor productivity due to many barriers that existed in the past and still remain today. This study explored the use of three dimensional modeling to enhance visualization of the industrial construction process to determine if labor productivity increases as a result of implementation. Not only did this study answer the research question, it showed that industrial construction research is possible and should be pursued by other researchers.

This study will contribute to the overall body of knowledge pertaining to labor productivity. Through positive empirical findings, the researcher is convinced that the use of three dimensional modeling will be implemented by more facility owners and construction firms to increase labor productivity. This utilization by the installation work crews during the construction process will aid in cost savings and improve schedule durations.

When the results of the study prove to be positive, the use of three dimensional modeling during the construction process could be an industry standard. This could open the door to explore the use of other technological advances in the construction industry. In addition, other researchers could gain more confidence to prepare research proposals and present to owner facilities and construction firms for similar type studies.

Limitations of the Study

This study was conducted in one industrial facility in southeastern Louisiana. An optimum study would include various facilities located throughout a particular region or the entire United States as a whole. In addition, this study had a limited number of subjects. This researcher generalized to the target population from the accessible population but did not claim representativeness since a random sample was not taken from the target population.

Industrial construction involves major disciplines such as civil, structural steel, piping, mechanical, electrical and instrumentation, insulation, and painting. This study focused on structural steel installation only simply due to the fact that this discipline of work was being performed at the selected construction site at the time of the study. In order to generalize to all aspects of industrial construction, other disciplines would have to be studied as well.

CHAPTER 2: REVIEW OF RELATED LITERATURE

Construction Labor Productivity

There are many definitions of construction labor productivity found in the literature.

Productivity is defined as a measure of economic efficiency which shows how effectively economic inputs are converted into output. Productivity is measured by comparing the amount of goods and services produced with the inputs which were used in production. Labor productivity is the ratio of the output of goods and services to the labor hours devoted to the production of that output (Bureau of Labor Statistics [BLS], 2014, para. 1 & 3).

Another confirming definition of construction labor productivity is the ratio of output generated to hours worked (Rojas & Aramvareekul, 2003).

The construction labor productivity index between 1964 and 1999 which was derived from the ratio of constant dollars of contracts and work hours of hourly workers steadily declined at a rate of -0.48% per year (Teicholz, Goodrum, & Haas, 2001). Teicholz et al. (2001) points out probable reasons of declining construction labor productivity include "... (1) inadequate training for workers and managers; (2) fewer younger workers entering the work-force; (3) more safety procedures; (4) increased complexity of projects; (5) greater time pressure on project completion; and (6) greater fragmentation of the work process" (pp. 427-428).

A few years later, an update to these statistics yielded the same troublesome results.

The productivity of the construction industry, as measured by constant contract dollars of new construction work per hourly work hour, has gradually declined (with some modest exceptions) over the past 40 years at an average compound rate of -0.59%/year (see Figure 1). This is particularly alarming when compared to the increasing labor productivity in all non-farm industries, which have experienced an increasing productivity of 1.77%/year over the same time period (Teicholz, 2004, para. 1).

The labor productivity indexes for the United States were determined by dividing constant contract dollars obtained from the Department of Commerce by jobsite worker labor hours for those contracts furnished by the Bureau of Labor Statistics (Teicholz, 2004). This data is represented for years 1964 through 2003 in Figure 1.

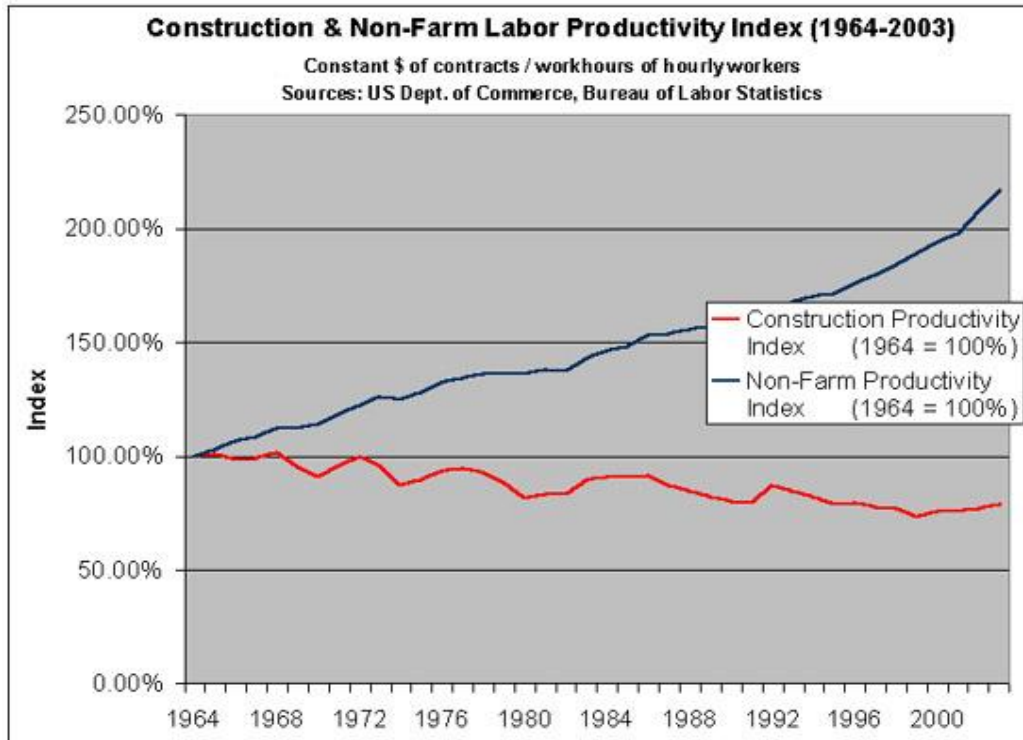


Figure 1. Construction & Non-Farm Labor Productivity Index (1964-2003). (Constant \$ of Contracts / Work Hours of Hourly Workers), [Adapted from U.S. Department of Commerce, Bureau of Labor Statistics], (Teicholz, 2004).

The most recent update found in the literature regarding these particular productivity indexes were presented for years 1964 through 2009. During this timeframe, the productivity of non-farm industries including the construction industry has more than doubled (Eastman, Teicholz, Sacks, & Liston, 2011). However, the construction labor productivity has been relatively unchanged but estimated to have a cumulative labor productivity loss of approximately 10 percent from year 1964 to 2009 (Eastman et al., 2011). The constant contract dollars included labor, materials, and delivery as well as architectural and engineering costs. (Eastman et al., 2011). The worker labor hours were strictly field installation hours excluding any off-site work such as pipe or steel fabrication (Eastman et al., 2011).

The Construction Industry Institute (2006) provided statistics from their benchmarking and metrics studies and concluded that construction industry productivity has gone down 25% over the past 15 years. During this same time period, productivity in manufacturing industries has gone up 125% (Construction Industry Institute, 2006).

In this research study, labor productivity is defined as the ratio of labor hours earned to the labor hours actually expended. The labor hours earned is formulated by multiplying the percent complete for a work item that has a corresponding estimated labor hour value derived from company or industry standards. For instance, if a 5 foot long W8x24 structural steel member is estimated to take two labor hours to install and this task is completely erected, the labor hours earned is calculated as follows: two hours x 100 % complete = two hours. So if 1.8 hours were expended to install this structural item, productivity will be calculated as follows:

Labor hours earned / Labor hours expended;

$$2.0 / 1.8 = 1.11.$$

Since the hours expended is less than the hours earned, we can determine a positive labor productivity rate.

Labor productivity in the construction industry lags behind other industries such as manufacturing. In manufacturing, productivity is achieved through the utilization of information systems, supply chain management, automation, and collaboration tools (Eastman et al., 2011). Possible reasons why these have not been effectively used in the construction industry include (Eastman et al., 2011):

- There are less than five employees in 65% of construction companies which makes it difficult to acquire new technology
- Wages adjusted for inflation and benefit packages have remained stagnate

- New construction work represents only approximately 64% of the total volume of projects. Remodeling, additions, repair, and maintenance represent the remaining volume. These “non-new” types of projects do not use capital intensive construction methods
- Primarily large construction firms adopt new and improved business practices. The smaller firms do not utilize these practices
- In order to include more construction firms in the bid submittal process, communication reverts back to paper based documents
- Construction projects have a limited time frame for execution and involve many different entities. There are few opportunities to experience improvements over time through applied learning which are realized in the manufacturing sector
- There has been limited automation at construction work sites due to the steady decline in hourly wages.

Adrian (2004) states that the reasons for low productivity include uniqueness of construction projects, varied locations, adverse and uncertain weather, climate seasonality, dependence on the economy, small size of firms, lack of research and development, restrictive building codes, regulations, laws, high percentage of labor cost, supply-demand characteristics, little potential for learning, risk of worker accident, work rules, lack of worker motivation, poor cost systems and control, working more than 40 hours in a given week, poor project planning, and poor planning for measuring and predicting productivity. Other factors affecting construction labor productivity include barriers to introducing new technologies, poor management, labor organization, real wage trends, and construction training (Allmon, Haas, Borcharding, & Goodrum, 2000).

Li et al. (2008) postulate that the decrease in construction labor productivity as compared to other non-farm industries may be explained by the construction industry not having an effective mechanism to capture and re-use knowledge gained in the design and construction phases, lack of a production line set-up, and the inability to “try before build”. To address these issues, virtual prototyping (VP) or process simulation in the construction industry could be utilized, however, the development and application has been limited (Li et al., 2008).

The construction industry as a whole acting through associations can increase productivity by selecting appropriate start dates, prefabricating components, changing labor work rules, developing research and development funds to enhance technological changes, lobbying to change certain laws and regulations, and funding more technical and management training (Adrian, 2004). Individual construction firms can increase labor productivity by instituting programs to motivate workers, pursuing new construction methods and materials, implementing innovative management techniques, outlining accounting and control procedures, and developing a separate department to address productivity issues (Adrian, 2004).

A research study conducted from data on industrial construction projects concluded that construction labor productivity was positively correlated with the usage of automation and integration of construction information systems (Zhai, Goodrum, Haas, & Caldas, 2009). In fact, the average time savings per installed quantity for structural steel was 37.7% (Zhai et al., 2009). The use of new technology can have a substantial positive impact on labor productivity in the construction industry (Adrian, 2004).

Three-Dimensional (3D) Modeling / Building Information Modeling (BIM)

Computer-aided design (CAD) was primarily developed to automate the function of manual drafting of construction plans. Early on, CAD represented two dimensional geometry

through graphical elements such as symbols, lines, arcs, etc (Howell & Batcheler, 2005).

Through technological evolution, two dimensional CAD has been transformed into three dimensions. Three-dimensional (3D) CAD encompasses geometry in the form of objects and functional relationships between building elements (Howell & Batcheler, 2005). This geometry enables visualization of construction processes for all stakeholders involved in a project.

There are many definitions found in the literature regarding Building Information Modeling (BIM). The McGraw Hill (2009) “The Business Value of BIM” Report defines BIM as, “The process of creating and using digital models for design, construction and/or operations of projects” (p. 4). The National Building Information Modeling Standard (2007) defines BIM as:

BIM is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder (pp. 20-21).

Hardin (2009) specifically explains “For a contractor, BIM is the virtual construction of a facility or structure that contains intelligent objects in a single source file that, when shared among project team members, intends to increase the amount of communication and collaboration” (p. 3). “BIM is the “process” of generating and managing building information in an interoperable and reusable way” (Lee, Sacks, & Eastman, 2006, p. 758).

The main difference between 3D CAD and BIM is that 3D CAD describes a project by independent three dimensional views such as sections, elevations, and plans (Azhar, Khalfan, & Maqsood, 2012). Changing one of these three dimensional views requires that all other views must be verified and updated (Azhar, Khalfan, & Maqsood, 2012). BIM includes all information related to the project such as its physical and functional characteristics (Azhar, Khalfan, &

Maqsood, 2012). If a change of a component is made in BIM, the program automatically adjusts and changes other components that are affected. This main difference stems from the fact that 3D CAD centers on data that are graphical depictions such as arcs, lines, and circles whereas BIM contains data represented by building elements such as spaces, beams, columns, and walls (Azhar, Nadeem, Mok, Leung, 2008). BIM carries the “intelligence” of the building components including project life cycle information (Azhar et al., 2008). However, BIM and 3D CAD both include the same three dimensional representation of a construction project for visualization purposes.

For the purposes of this research, Building Information Modeling (BIM) and the term three-dimensional (3D) CAD or modeling will be used interchangeably. Even though there are differences as discovered in the literature, the researcher will focus on the visualization aspects of BIM and 3D modeling. In a way, BIM’s major component is its three dimensional features that provide visualization. However, BIM incorporates information and technical data into the components to enable its “intelligence”.

Survey research conducted in 2007 and 2008 by Suermann and Issa (2009) assessed perceptions about the implementation of BIM on construction projects. The survey data was collected from various sources and some interesting perceptions about BIM and construction productivity were discovered. The first survey was administered in 2007 to the National Institute of Building Sciences (NIBS), Facility Information Council (FIC), and National BIM Standard (NBIMS) committee members. This survey indicated that 76% of respondents felt that BIM improves or maximizes a key performance indicator denoted as “units per man-hour” which represents a measure of completed units put in place per individual man-hour of work (Suermann & Issa, 2009). The second survey was open to the entire construction industry and advertised in

various media outlets and included the Associated Schools of Construction (ASC), American Institute of Architects (AIA), Associated General Contractors of America (AGC), American Society of Civil Engineers Construction Institute (ASCE-CI), United States Army Corps of Engineers (USACE), Society of American Military Engineers, Architects, Engineers, and Contractors (AEC Café), Geographical Information Systems (GIS Café), “upFront – eZine” (sic), and the Science and Technology for Architecture, Engineering, and Construction Annual BIM Conference (AEC-ST, May 15-17, 2007) in Anaheim, CA. This survey indicated that 67% of respondents felt that BIM improves or maximizes “units per man-hour” (Suermann & Issa, 2009). The third survey was administered in 2008 to attendees of the BIM4Builders™ Event in Gainesville, Florida. This survey research indicated that 74.9% of respondents felt that BIM improves construction productivity (Suermann & Issa, 2009).

A research case study involved the use of BIM for the mechanical, electrical, and plumbing (MEP) systems on a \$96.9 million healthcare project in Mountain View, California. The Camino Medical Group project included a medical office building with over 250,000 square feet that was completed in 2007. The MEP systems for the project were challenging due to the complexity and nature of the building design (Khanzode, Fischer, & Reed, 2008). The benefits achieved through the use of BIM for the MEP systems included 20 to 30% labor cost reductions for the MEP subcontractors, rework being less than 0.2% on the mechanical portion of the project, a six month schedule improvement, overall project cost savings of \$9 million, and labor productivity improvements between 5 to 25% for the mechanical portion (Khanzode, Fischer, & Reed, 2008).

Another research study entailed constructing a \$6 million pilot plant facility utilizing BIM within an existing warehouse for Sequus Pharmaceuticals located in Menlo Park,

California. The project comprised of 20,000 square feet of available space and was completed in 1999. There were many benefits of utilizing BIM such as the project being completed on schedule and below the anticipated construction costs (Khanzode & Staub-French, 2007). During the constructability phase, most design conflicts were identified resulting in higher productivity. All MEP subcontractors experienced increases in construction productivity. Interestingly, the mechanical subcontractor would utilize the 3D model and print piping components for the construction crews to use during the installation process (Khanzode & Staub-French, 2007). This application of the 3D model in the construction phase indicates more research needs to be conducted to explore productivity gains. The study noted that the benefits gained by BIM did encounter some offsets such as increased design time and coordination. However, the increased efficiency and less rework of the installation process more than accounted for the increased design cost and time (Khanzode & Staub-French, 2007).

The Stanford University Center for Integrated Facilities Engineering (CIFE) consolidated data from 32 major projects using BIM and reported benefits such as nearly 10% cost savings of the contract budget through clash detections and a 7% reduction in project duration (CIFE, 2007).

A case study involved BIM being used for a \$201 million biomedical facility comprising of 11 stories and 540,000 square feet. The project was labeled “Research 2” for the University of Colorado-Denver Health Sciences Center in Aurora, Colorado due to a similar biomedical facility built previously titled “Research 1”. In fact, the two facilities were adjacent to one another. The Research 1 project was built without utilizing BIM. This situation presented an excellent opportunity to compare the data from the two projects. The steel subcontractor was able to produce 3D shop drawings for review and approval in one package (McGraw Hill, 2009).

The structural engineers were able to review and approve the drawings for fabrication without delay. This deviated from the normal process of submitting drawings for approvals in separate packages. Some of the BIM benefits realized in this project included (McGraw Hill, 2009):

- Structural steel being erected six weeks ahead of schedule
- Reduction in construction Request for Information (RFIs)
- Reduction in rework due to early coordination
- Significant schedule gains - two months ahead of schedule and six months ahead of the similar Research 1 Project.

Another case study was based on a high explosives pressing facility for the U.S. Department of Energy's National Nuclear Security Administration. The Pantex Complex project was valued at \$100 million, 45,000 square feet in size, and located in Amarillo, Texas. Some of the benefits of utilizing BIM included (McGraw Hill, 2009):

- Thousands of collisions were identified by using clash detection software
- Over 500 serious problems were identified by virtually "walking through" every room with the operations staff
- \$10 million savings generated
- Using BIM to train employees at the facility before occupancy resulting in saving months out of the traditional start-up phase.

Akanmu, Anumba, and Messner (2011) concluded that BIM provides an avenue for visualization which can lead to reducing construction cost and schedule duration, and increasing productivity. By using the 3D model and radio frequency identification (RFID) tags with the actual construction, structural steel installation could be enhanced (Akanmu et al., 2011). BIM

has been primary used for visualization in the pre-construction phase of a project (Gilligan & Kunz, 2007).

Architects, although in the commercial sector, indicate that BIM can improve productivity and is ranked as the highest way to improve return on investment (ROI) in technology applications (McGraw Hill, 2009). In addition, visualization of the design can benefit owners during a project (McGraw Hill, 2009).

During a 2007 American Institute of Steel Construction (AISC) and American College of Construction Lawyers (ACLL) eConstruction Roundtable event, Hartmann and Fischer (2008) discussed that a number of projects were able to realize a 20-30% higher productivity at the jobsite through the utilization of BIM that lead to no field interferences and a reduction of field change orders and requests for information (RFI) (Hartmann and Fischer, 2008). However, the steel industry's viewpoint of obstacles to BIM includes problems with financial risk, fear of change, and legal frameworks (Hartmann & Fischer, 2008). One of the general contractor's viewpoints of obstacles to BIM includes the problem of not having the 3D model available from the designer (Hartmann & Fischer, 2008).

A case study involved the Hilton Aquarium Project located in Atlanta, Georgia. This case study indicated cost and time savings due to developing and using BIM for an actual construction project. The data was provided by Holder Construction Company, Atlanta, Georgia. The project entailed a \$46 million hotel (484,000 square feet) and a parking structure. Holder Construction created 3D models of the architectural, structural, and MEP systems which enabled the project team to conduct 3D coordination sessions (Azhar, Hein, & Sketo, 2008). As a result, the team was able to identify and resolve system conflicts. During the construction process, visualization models were made available to all parties involved in the project. The study

findings included an estimated \$600,000 savings related to extras, eliminating months of potential delays, and an improvement of the schedule by 1,143 hours (Azhar, Hein, & Sketo, 2008). However, the results reported were based on estimates of savings for conflicts eliminated during the pre-construction process and not on actual data gathered from the construction phase (Ilozor & Kelly, 2012).

The One Island East Project provided a case study involving a large \$300M commercial office building with seventy floors (1,517,711 square feet) in Hong Kong, China. The One Island East Project implemented BIM to manage all functions between design, construction, and facility management. The owner identified the potential of BIM to manage information more efficiently and save time and cost over the project life cycle (Azhar et al., 2008). There were more than 2,000 clashes and errors that were identified prior to bidding and construction which resulted in cost savings achieved from the clash detection (Azhar et al., 2008).

Gilligan and Kunz (2007) conducted research and gathered 2007 data based on a combination of 171 respondents to a web-based survey and 45 individual follow-up interviews with respondents who volunteered to be contacted in order to determine the value from BIM usage and the factors that contribute to success. The majority of respondents reported increases in productivity on their projects due to unintended consequences from using Virtual Design and Construction (VDC) methods (Gilligan and Kunz, 2007). The interviews with respondents indicate that the largest cost savings from VDC originate from prefabrication of construction component such as piping, ducting, and structural steel at off-site fabrication shops (Gilligan and Kunz, 2007). One of the main findings of their study included that most companies use BIM for clash detections, planning, and visualization. Another main finding demonstrated that the use of BIM leads to increases of productivity (Gilligan & Kuntz, 2007).

Nawari (2012) concluded the use of BIM leads projects to be visualized in three dimensions before on-site construction and provides a significant impact on off-site construction because it enhances constructability, quality, safety of the work environment, and prefabrication output. BIM can act as a tool to improve collaboration and communication, eliminate inefficiencies and redundancies, and enhance overall productivity (Campbell, 2007).

The use of 3D modeling in the architecture, engineering, and construction (AEC) industry has primarily been limited to certain properties of design visualization (Campbell, 2007). Construction planners, schedulers, owners, and engineering groups benefit from the visualization aspect of 3D modeling during the pre-conception, design, constructability, and pre-construction phases (Campbell, 2007). However, 3D modeling usage needs to expand into the construction component installation process in order to realize the full potential of this technology that is currently available but seldom used for visualization purposes. BIM has spatial characteristics to better represent complex construction conditions in a three dimensional realm rather than two dimensional drawings (Campbell, 2007).

During the One Island East 70-story office building project located in Hong Kong, pictures or model shots were taken from the 3D or virtual prototype (VP) model and given to construction field crews and subcontractors as visualized work instructions (Li et al., 2008). This enabled the construction personnel to visualize the work process before performing any tasks. A picture of the actual workers and a three dimensional model shot are indicated in Figure 2.

Deficiencies/Limitations in the Literature

Although there has been widespread literature to argue that construction productivity has declined, the uncertainty surrounding the process of computing values used in the determining labor productivity has raised speculation to whether productivity has actually remained constant, increased, or decreased in the construction industry (Rojas & Aramvareekul, 2003).

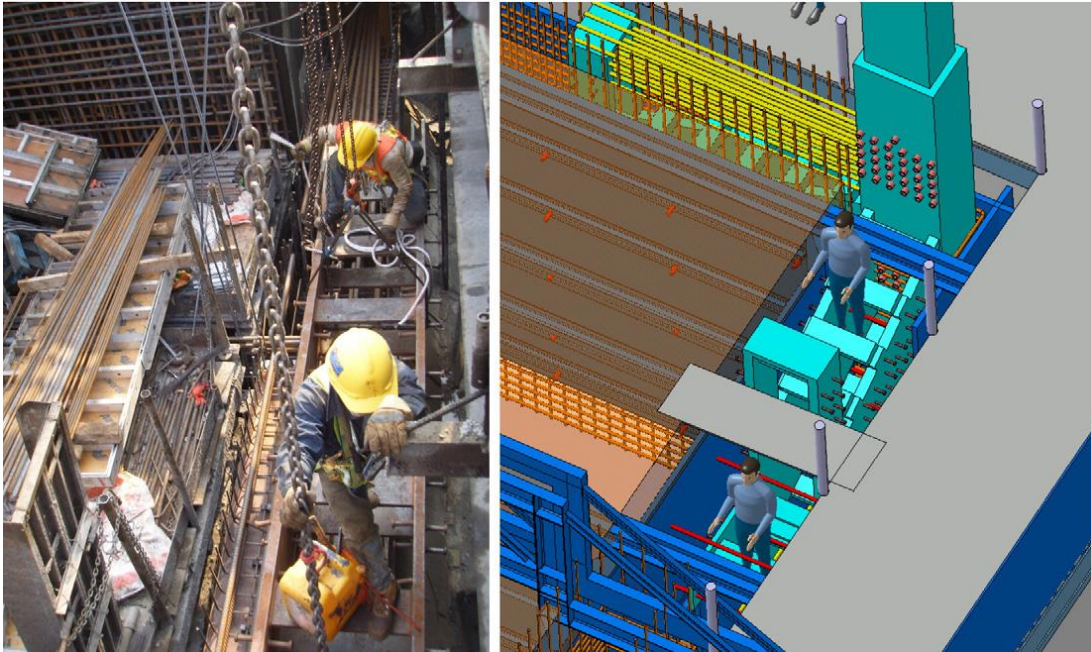


Figure 2. Visualized work instruction versus the real installation (Li et al., 2008)

There appears to be a significant gap in both the research conducted and the scholarly articles published in the area of BIM and 3D CAD modeling regarding the utilization of the visualization aspect of the software for construction workers during project execution. There is little experimental research to determine if the use of 3D modeling for visualization purposes can improve construction labor productivity and other key performance indicators (KPI). Barlish and Sullivan (2012) point out that “The utilization of BIM has not been empirically and clearly established to be beneficial to the overall outcome of a construction project. Owners are faced with the dilemma of making a decision of whether or not to utilize BIM based on speculated benefits” (p. 150).

Owners, engineers, and contracting firms need hard evidence that 3D modeling or BIM actually pays dividends. Once empirical evidence through research is made available that demonstrates the benefits of 3D modeling or BIM, there will be the possibility of full

implementation to help improve efficiencies in the construction industry. Although literature expresses the heralded benefits of BIM as a mechanism of increasing productivity, there are limited amount of metrics that measure improvements in productivity (Succar, Sher, & Williams, 2012).

Throughout the literature review, there were surveys, case studies, interviews, and generalizations regarding the benefits of BIM and 3D modeling. However, there seems to be a lack of empirical data to support some of the claims. The literature does not provide quantifiable metrics to interpret return on investments (Barlish & Sullivan, 2012). In addition, there are limited studies that provide meaningful statistical results to understand the impact of 3D CAD technology on improving existing construction processes (Park, Kim, B., Kim, C., & Kim, H., 2011).

Ilozor and Kelly (2012) state “There is a lack of thorough quantitative analysis and rigorous independent verification of the many qualitative assertions made within the literature with respect to BIM’s potential positive impact on productivity, cost, schedule, quality, etc” (p. 28). Due to non-empirically based findings in the literature, there is a need for more rigorous quantitative analysis of return on investments, cost savings, and productivity increases actually experienced by construction firms utilizing BIM technology (Ilozor & Kelly, 2012).

The use of BIM has many advantages as outlined above. The researcher was surprised to find little research done to quantify the benefits of BIM or 3D modeling. Of the research done, the vast majority related to commercial construction. However, studies that include BIM for mechanical, electrical, and plumbing (MEP) of commercial projects do provide a basis for its use in the industrial sector (Fortner, 2010). With that being said, there is a definite need for more studies of BIM or 3D modeling use in the industrial construction industry.

Conceptual Framework for the Study

The conceptual framework for the study centers on the visualization aspect of installing construction components provided by the three dimensional pictures or model shots of BIM or 3D CAD modeling software. Visualization is the graphic representation of data, information and knowledge that can provide advantages to the cognitive, social, and emotional challenges faced by many organizations (Eppler & Platts, 2009).

Visualizing the construction process involves being able to view in a virtual environment, the interaction of the various resources as they build the facility with the passage of time. These resources include, but are not limited to temporary structures, materials, equipment, and labor as they create the product (Kamat & Martinez, 2000, p. 507).

Being capable to visualize the process of installing construction components before actually performing that function is vital to effective project execution and achieving efficiency in the work force. Using the 3D model to understand how construction parts fit within a defined space and how other components may affect installation, the construction worker is enabled to achieve an understanding of the relationships between components.

CAD modeling has been used for many years in the pre-construction phase of industrial, heavy, and building construction industries (AbouRizk & Mather, 2000). The most apparent benefit of utilizing 3D modeling is the communication aspect to engage all the stakeholders such as planners, architects, consultants, and contracting firms. (Gao, Fischer, Tollefsen, & Haugen, 2005).

The construction industry does a poor job of measuring the outcomes of technology improvements and the quality of construction output (Goodrum, Zhai, and Yasin, 2009). This leads to a perception issue that the construction industry is technologically stagnant (Goodrum, Zhai, and Yasin, 2009). There is a need for visual tools to enhance production management during the construction phase due to the physical conditions of construction sites that present

challenges for most workers to form clear mental images of the installation process (Sacks, Treckmann, & Rozenfeld, 2009).

Summary

Researchers face a daunting task to acquire actual industrial construction data to use in statistical analysis. Acquisition of data from construction projects is hindered by characteristics of the industry itself. Owners of industrial facilities rely on contracting firms to produce at high productivity levels. Contracting firms have not embraced the technology and usefulness of research to aid in increasing productivity. In addition, project construction sites are subject to different and uneven data due to the uniqueness of construction site conditions (Han & Halpin, 2005).

Industrial construction is comprised of building, expanding, and maintaining facilities in industries such as chemical production, petroleum refining, nuclear power, and other gas production. The industrial construction work disciplines include but not limited to civil, structural steel, piping, mechanical, electrical, instrumentation, insulation, refractory, fireproofing, painting, stress relieving, and non-destructive examinations. “Construction engineers agree that industrial construction is much more complex and uncertain than building and infrastructure construction” (Wang & AbouRizk, 2009, p. 1518). With the aid of a 3D model, the owner, engineer, construction personnel, and others interested in the construction project are able to visualize the completed product before it is actually built (Rivard et al., 2004).

Having a means to increase productivity at construction sites is very important to the owner, engineering firm, and contracting organization. However, in industrial construction the safety of employees is a vital concern and frankly one of the most important issues facing the industry. The use of BIM or 3D modeling can be implemented into new employee orientations, site specific safety plans, pre-task planning, job hazard analysis, accident investigations, job

training, and education (Clarke and Rajendran, 2011). Further research must be conducted to evaluate the use of BIM or 3D modeling to increase labor productivity as well as enhance safety performance.

Information technology implementation does have a positive effect on construction productivity (Zhai et al., 2009). Teicholz (2004) suggests that the introduction of 3D object-based CAD is one of the most important new approaches to construction productivity improvement to allow improved team collaboration, design, and construction planning and execution during all phases of a project's life cycle. "We should not expect construction productivity improvements without a significant change in the information tools and collaboration strategies used for design and construction" (Teicholz, 2004, para. 13).

CHAPTER 3: METHODOLOGY

Research Design

This research study utilized a one-group pretest-posttest time series design. Since the timing of this experiment coincided with an ongoing industrial construction project, the individuals were previously assigned to the project therefore no random sampling was possible. After three weeks of obtaining weekly labor productivity measures (dependent variable), this researcher introduced the independent variable or treatment (using 3D CAD model shots) to the individuals in the experiment. These individuals were provided letter size color 3D model shots of the particular steel members they were installing as well as their normal installation drawings and information. The dependent variable was measured weekly during the subsequent three weeks.

This particular research design was selected based on the parameters of the experiment and the actual settings at the construction site. There were a limited number of subjects in the study but dependent variable measures were taken multiple times on each subject. In addition, the individuals acted as their own control which benefited the study due to the small number of experimental subjects.

Population and Sample

The target population for this study was industrial construction workers in the southeastern region of the United States. This researcher's accessible group was industrial construction workers installing structural steel during the time of this study at a selected southeastern Louisiana chemical plant facility. The accessible group for this study consisted of 41 individuals.

Instrumentation

In order to calculate the dependent variable in this study, there were two components that needed to be determined. The two components consisted of the labor hours expended and the labor hours earned for each individual. The instrument used to collect the labor hours expended was the company's timesheet (See Appendix A). The foreman of each work crew recorded the hours expended and work tasks for each individual daily. The work tasks for each individual were recorded with cost accounting codes used for cost and progress reporting. The general foreman and steel superintendent approved the hours expended with the corresponding cost codes for the day. The timekeeper verified the expended hours with the corresponding start and end times indicated by a computerized gate entry and exit system. This researcher received a copy of the timesheets.

The instrument used to collect the labor hours earned was the company's progress reporting system. This reporting system calculated the labor hours earned from the completion percentage and the estimated hours for a particular work item for all work crews. The project planner developed the foreman's reports used for updating the progress on the project. The report listed each activity or work item that the workers were installing (See Appendix B). Each work activity had a corresponding estimated hour value. Based on information provided by the foremen and daily inspection, the general foreman used the report to indicate the completion percentage for each work item. The project planner used the completion percentage to "update" the progress reporting system. Once the reporting system was updated, earned labor hours were calculated. This researcher received a copy of the progress reports from the planner. The following is an example to illustrate the labor productivity calculation:

A W10 x 35 steel member 10' long has an estimated installation labor value of 5.5 hours. If the steel member is installed, bolting has been verified, and the quality control department has accepted the installation, the supervisor or foreman can show progress on that work item as being 100% complete. The planner will update the progress reporting system and the earned labor hours will be calculated as 5.5:

Earned labor hours = estimated labor hours x % complete

Earned labor hours = 5.5 x 100% = 5.5.

If the labor hours expended to install the W10 x 35 steel member equals 4.0, the labor productivity will be calculated as:

Earned labor hours / expended labor hours

5.5 / 4.0 = 1.375 labor productivity.

Since the hours expended is less than the hours earned, we can determine a positive labor productivity rate.

Based on the progress reports from the planner, this researcher used foreman daily work tickets, interviews with the general foreman, and field observations to determine individual earned hours.

The company developed and has been using the progress reporting system for over twenty five years. Over these years, the company's clients have been completely satisfied with the accuracy and reliability of the progress reporting system. Based on a proven track record in the industrial construction sector, these instruments are valid and reliable.

The instrument used to collect the worker classification was the company's timesheets. This researcher was provided a copy of the timesheets. The instrument used to collect the total

years of construction experience, frequency of looking at the three dimensional model shots, and perceived helpfulness of the three dimensional model shots was a posttest survey (See Appendix C). This researcher provided the steel superintendent with the posttest survey for distribution to the foremen and steel workers for completion. The age and gender of each individual in the study were provided by the company.

Data Collection

Upon approval to proceed from the Louisiana State University Institution Review Board (See Appendices D and E) and dissertation advisory committee, this researcher employed a comprehensive plan to collect data for the study. A meeting was conducted with the company's project manager, site manager, project controls manager, steel superintendent, steel general foreman, and planner to discuss the research study in detail. Structural steel installation workers and their foremen were identified for the study. Over the course of three weeks, timesheets and progress reports indicating labor hours expended and earned were received weekly from the timekeeper and planner. This researcher used foreman daily work tickets, interviews with the general foreman, and field observations to determine individual earned hours from the progress reports. In addition, this researcher calculated productivity measures for each week based on this information using the following formula:

$$\text{Productivity measure} = \text{Earned labor hours} / \text{Expended labor hours}.$$

These weekly measures represented pretest scores.

After three weeks, this researcher generated and provided letter size color 3D model shots of the particular steel members being installed to the general foreman in order to share with each foreman and the steel workers in the study. The steel workers utilized the 3D model shots as well

as their normal drawings, information, and direction from their foreman to install structural steel members for a three week period. During these three weeks, timesheets and progress reports indicating labor hours expended and earned were received weekly from the timekeeper and planner. This researcher used foreman daily work tickets, interviews with the general foreman, and field observations to determine individual earned hours from the progress reports. In addition, this researcher calculated productivity measures for each week based on this information. These weekly measures represented posttest scores.

After receiving the company's timesheets, the worker classification for each individual was determined. In addition, a posttest survey was administered and the total years of construction experience, frequency of looking at the three dimensional model shots, and perceived helpfulness of the three dimensional model shots were obtained. The age and gender of each individual in the study were provided by the company.

Data Analysis

The data for this research study was analyzed according to each objective as outlined below.

Objective One

Objective one of the study was to describe industrial construction workers that were working on a project in a selected industrial facility in southeastern Louisiana on the following selected personal and professional demographic characteristics:

- i. age
- ii. gender
- iii. total years of construction experience

iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc). This classification was based on the number of years of experience in construction, how long the worker had been at other classification levels, and scores on standardized written craft examinations given by the company. Other criteria used in the evaluation included if the worker had formal craft training and certifications in programs such as those offered through the Associated Builders and Contractors or the National Center for Construction Education and Research (NCCER).

v. frequency of looking at the three dimensional model shots

vi. perceived helpfulness of the three dimensional model shots.

The data collected was analyzed using the descriptive statistics function in the SPSS statistical software. Age, total years of construction experience, frequency of looking at the three dimensional model shots, and perceived helpfulness of the three dimensional model shots were interval variables. Gender and worker classification were nominal variables. These variables were summarized using frequencies, percentages, means, and standard deviations.

Objective Two

Objective two of the study was to determine the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana on three consecutive weekly measures taken before introducing three dimensional modeling. These labor productivity measures were the pretest scores.

The data collected was analyzed and used in the following calculation:

Labor productivity = earned labor hours / expended labor hours.

Data was summarized using means and standard deviations.

Objective Three

Objective three of the study was to determine the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana on three consecutive weekly measures taken after introducing three dimensional modeling. These labor productivity measures were the posttest scores.

The data collected was analyzed and used in the following calculation:

Labor productivity = earned labor hours / expended labor hours.

Data was summarized using means and standard deviations.

Objective Four

Objective four of the study was to compare the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana before introducing three dimensional modeling with each of the three consecutive weekly measures taken after introducing three dimensional modeling.

The data collected was compared using the paired t-test procedure in the SPSS statistical software.

Objective Five

Objective five of the study was to determine if a model exists explaining a significant portion of the variance in the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana before introducing three dimensional modeling from the following selected personal and professional demographic characteristics:

- i. age
- ii. gender

iii. total years of construction experience

iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc).

The data collected was analyzed using multiple regression analysis in the SPSS statistical software. The independent variables were age, gender, total years of construction experience, and worker classification. The dependent variable was the labor productivity scores before introducing three dimensional modeling. The variables were entered using stepwise procedures due to the exploratory nature of the study.

Objective Six

Objective six of the study was to determine if a model exists explaining a significant portion of the variance in the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana for each of the three weeks after introducing three dimensional modeling from the following selected personal and professional demographic characteristics:

i. age

ii. gender

iii. total years of construction experience

iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc)

v. frequency of looking at the three dimensional model shots.

The data collected was analyzed using multiple regression analysis in the SPSS statistical software. The independent variables were age, gender, total years of construction experience, worker classification, and frequency of looking at the three dimensional model shots. The dependent variable was the labor productivity scores after introducing three dimensional

modeling. The variables were entered using stepwise procedures due to the exploratory nature of the study.

Louisiana State University Institutional Review Board Approval

Permission to perform the study was granted by the Institutional Review Board (IRB) at Louisiana State University.

CHAPTER 4: RESULTS

The primary purpose of this study was to determine if the use of three dimensional (3D) modeling to enhance visualization of structural steel installation will increase labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana.

The following specific objectives were designed to facilitate this research study:

1. Describe industrial construction workers that were working on a project in a selected industrial facility in southeastern Louisiana on the following selected personal and professional demographic characteristics:
 - i. age
 - ii. gender
 - iii. total years of construction experience
 - iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc)
 - v. frequency of looking at the three dimensional model shots
 - vi. perceived helpfulness of the three dimensional model shots.
2. Determine the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana on three consecutive weekly measures taken before introducing three dimensional modeling.
3. Determine the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana on three consecutive weekly measures taken after introducing three dimensional modeling.
4. Compare the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana before introducing three dimensional modeling with each of the three consecutive weekly measures taken after introducing three dimensional modeling.

5. Determine if a model exists explaining a significant portion of the variance in the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana before introducing three dimensional modeling from the following selected personal and professional demographic characteristics:
 - i. age
 - ii. gender
 - iii. total years of construction experience
 - iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc).
6. Determine if a model exists explaining a significant portion of the variance in the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana with each of the three weeks after introducing three dimensional modeling from the following selected personal and professional demographic characteristics:
 - i. age
 - ii. gender
 - iii. total years of construction experience
 - iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc)
 - v. frequency of looking at the three dimensional model shots.

The target population for this study was industrial construction workers in the southeastern region of the United States. This researcher's accessible group was industrial construction workers installing structural steel at a selected southeastern Louisiana chemical plant facility at the time of this study. The accessible group consisted of 41 individuals. This

chapter provides the findings of the study. The results are organized by each specific objective of the study.

Objective One: Results

The first objective of this study was to describe industrial construction workers that were working on a project in a selected industrial facility in southeastern Louisiana on the following selected personal and professional demographic characteristics:

- i. age
- ii. gender
- iii. total years of construction experience
- iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc)
- v. frequency of looking at the three dimensional model shots
- vi. perceived helpfulness of the three dimensional model shots.

This objective utilized data from 41 individuals that were associated with installing structural steel. The variables age, total years of construction experience, frequency of looking at the three dimensional model shots, perceived helpfulness of the three dimensional model were interval variables and were summarized using frequencies, percentages, means, and standard deviations. The variables gender and worker classification were nominal variables and were summarized using frequencies and percentages. The results for each of these personal and professional demographic characteristics are as follows:

Age

The variable age for each individual was derived from company records. The mean age in years was 35.4 (SD = 10.67). The largest number of subjects were in the “21-30” year age group (n = 18 or 43.9%). There were no individuals under the age of 21. The second largest group was in the “31-40” age category (n = 11 or 26.8%). The other two age groups “41-50” and “51-60”

had the identical statistics ($\underline{n} = 6$ or 14.65%). There were no individuals over the age of 60. The results are presented in Table 1.

Table 1.
Age of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Age in years	Frequency	Percent
< 21	0	0.0
21-30	18	43.9
31-40	11	26.8
41-50	6	14.65
51-60	6	14.65
>60	0	0.0
Total	41	100.0

Note. Mean age = 35.4, $\underline{SD} = 10.67$

Gender

The variable gender for each individual was derived from company records. All individuals were male ($\underline{n} = 41$, 100%).

Total Years of Construction Experience

Another variable used to describe the individuals in the study was the total years of construction experience. Data on this variable was gathered by asking the individuals in the study on a posttest survey their total years of construction experience. The mean total years of construction experience was 12.4 ($\underline{SD} = 8.45$). The largest number of subjects were in the “6-10”

year construction experience group ($\underline{n} = 20$ or 55.6%). The “11-15” and “16-20” year construction experience groups had the second largest number of individuals ($\underline{n} = 4$ or 11.1%). The smallest group was in the “21-25” year construction experience category ($\underline{n} = 1$ or 2.8%). The total years of construction experience ranged from 1 to 35. Of the 41 individuals being described, only data from 36 individuals related to total years of construction experience were obtained. The results are presented in Table 2.

Table 2.

Total Years of Construction Experience of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Total Years Construction Experience	Frequency	Percent
1-5	3	8.3
6-10	20	55.6
11-15	4	11.1
16-20	4	11.1
21-25	1	2.8
26-30	2	5.55
31-35	2	5.55
>35	0	0.0
Total	36 ^a	100.0

Note. Mean total years of construction experience = 12.4, $\underline{SD} = 8.45$

^a5 of the individuals in the study did not provide data on their total years of construction experience

Worker Classification

Another variable used to describe the individuals in the study was the worker classification. The worker classifications were obtained from the company's timesheets. The majority of the subjects were classified as "Mechanic A" ($\underline{n} = 29$ or 70.7%). The other subjects were classified as either "General Foreman", "Foreman", "Mechanic B", "Mechanic C", "Helper I", or "Helper III" ($\underline{n} = 12$ or 29.3%). The results are presented in Table 3.

Table 3.
Classifications of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Worker Classification	Frequency	Percent
Mechanic A	29	70.7
Foreman	4	9.8
Helper I	4	9.8
Helper III	1	2.4
Mechanic B	1	2.4
Mechanic C	1	2.4
General Foreman	1	2.4
Total	41	100.0

Frequency of Looking at the Three Dimensional Model Shots

Another variable used to describe the individuals in the study was the frequency of looking at the three dimensional model shots. Data on this variable was gathered by asking the individuals in the study: “How often did you look at the 3D model shots (computer pictures)?” on a posttest survey. The subjects could indicate: “never”, “very little”, “occasionally”, “several times”, or “many times”. This researcher created the following scale to aid in the interpretation of the responses: 1 = never, 2 = very little, 3 = occasionally, 4 = several times, and 5 = many times. The mean frequency of looking at the three dimensional model shots was 2.5 ($SD = 1.09$). The majority of the subjects indicated that they looked at the three dimensional model shots either “occasionally”, “several times”, or “many times” ($n = 20$ or 57.1%). The largest number of subjects indicated that they “occasionally” looked at the three dimensional model shots ($n = 14$ or 40.0%). There was one individual in the study that indicated he looked at the three dimensional model shots “many times” ($n = 1$ or 2.9%). Of the 41 individuals being described, only data from 35 individuals was received for this variable. The results are presented in Table 4.

Table 4.
Frequency of Looking at the Three Dimensional Model Shots of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Looking at the 3D Model Shots ^a	Frequency	Percent
Never	8	22.9
Very Little	7	20.0
Occasionally	14	40.0
Several Times	5	4.2

(Table 4 continued)

Looking at the 3D Model Shots ^a	Frequency	Percent
Many Times	1	2.9
Total	35	100.0

Note. Mean frequency of looking at the three dimensional model = 2.5, SD = 1.09;
Response Scale: 1 = never, 2 = very little, 3 = occasionally, 4 = several times, and 5 = many times

^aHow often did you look at the 3D model shots (computer pictures)?

Perceived Helpfulness of the Three Dimensional Model Shots

The last variable used to describe the individuals in the study was perceived helpfulness of the three dimensional model shots. Data on this variable was gathered by asking the individuals in the study: “How helpful did you find the 3D model shots?” on a posttest survey. The subjects could indicate: “not at all helpful”, “a little helpful”, “fairly helpful”, “helpful”, or “very helpful”. This researcher created the following scale to aid in the interpretation of the responses: 1 = not at all helpful, 2 = a little helpful, 3 = fairly helpful, 4 = helpful, and 5 = very helpful. The mean perceived helpfulness of the three dimensional model shots was 2.8 (SD = 1.26). The majority of the subjects indicated that the three dimensional model shots were either “fairly helpful”, “helpful”, or “very helpful” (n = 20 or 57.1%). The largest number of subjects indicated that the three dimensional model shots were “helpful” (n = 11 or 31.4%). The smallest number of subjects indicated that the three dimensional model shots were “very helpful” (n = 2 or 5.7%). Of the 41 individuals being described, only data from 35 individuals was received for this variable. The results are presented in Table 5.

Table 5.

Perceived Helpfulness of the Three Dimensional Model Shots of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Perceived Helpfulness of the 3D Model Shots ^a	Frequency	Percent
Not at all Helpful	7	20.0
A Little Helpful	8	22.9
Fairly Helpful	7	20.0
Helpful	11	31.4
Very Helpful	2	5.7
Total	35	100.0

Note. Mean frequency of perceived helpfulness of the three dimensional model shots = 2.8, SD = 1.26;

Response Scale: 1 = not at all helpful, 2 = a little helpful, 3 = fairly helpful, 4 = helpful, and 5 = very helpful

^aHow helpful did you find the 3D model shots?

Objective Two: Results

The second objective of the study was to determine the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana on three consecutive weekly measures taken before introducing three dimensional modeling. These labor productivity measures were the pretest scores.

Out of the total group of 41 individuals in the study, this objective utilized data collected from 39 individuals that were associated with installing structural steel during the first three weeks of the study. The labor hours expended and earned for each of the 39 subjects were

summarized using frequencies, percentages, ranges, means, and standard deviations. The labor productivity for each of the 39 subjects was calculated from the labor hours earned and expended according to the following calculation:

$$\text{Labor productivity} = \text{earned labor hours} / \text{expended labor hours}.$$

The labor productivity for each of the 39 subjects was summarized using frequencies, percentages, ranges, means, and standard deviations.

The mean expended labor hours for week one of the study was 31.3 (SD = 6.71). During week one, the largest number of subjects worked between 35-40 hours (n = 17 or 48.5%). The second largest group of individuals worked between 30-34 hours (n = 10 or 28.6%). There was one individual that worked less than 20 hours during the first week (n = 1 or 2.9%). There were no individuals who worked greater than 40 hours. The expended hours ranged from 5.0 to 37.0. Of the 41 individuals in the study, expended hours were obtained from 35 individuals during week one. The results are presented in Table 6.

The mean expended labor hours for week two of the study was 37.5 (SD = 10.40). During week two, the largest number of subjects worked greater than 40 hours (n = 21 or 56.8%). The second largest group of individuals worked between 35-40 hours (n = 9 or 24.3%). There was one individual that worked between 20-24 hours during the second week (n = 1 or 2.7%). There were no individuals who worked between 30-34 hours. The expended hours ranged from 9.0 to 44.5. Of the 41 individuals in the study, expended hours were obtained from 37 individuals during week two. The results are presented in Table 6.

The mean expended labor hours for week three of the study was 50.7 (SD = 9.07). During week three, the largest number of subjects worked greater than 40 hours (n = 36 or 92.2%). There were no individuals who worked between 25-29 and 30-34 hours. The expended hours

ranged from 17.6 to 58.0. Of the 41 individuals in the study, expended hours were obtained from 39 individuals during week three. The results are presented in Table 6.

Table 6.

Expended Hours for Three Consecutive Weeks Before Introducing Three Dimensional Modeling of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Expended Hours	Week 1		Week 2		Week 3	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
< 20	1	2.9	3	8.1	1	2.6
20-24	3	8.6	1	2.7	1	2.6
25-29	4	11.4	3	8.1	0	0.0
30-34	10	28.6	0	0.0	0	0.0
35-40	17	48.5	9	24.3	1	2.6
> 40	0	0.0	21	56.8	36	92.2
Total	35 ^a	100.0	37 ^b	100.0	39 ^c	100.0

Note. Week 1 Mean expended hours = 31.3, SD = 6.71, Range = 5.0 – 37.0

Week 2 Mean expended hours = 37.5, SD = 10.40, Range = 9.0 – 44.5

Week 3 Mean expended hours = 50.7, SD = 9.07, Range = 17.6 – 58.0

^a6 of the individuals in the study did not have expended hours for week 1

^b4 of the individuals in the study did not have expended hours for week 2

^c2 of the individuals in the study did not have expended hours for week 3

The mean earned labor hours for week one of the study was 40.0 (SD = 9.27). During week one, the largest number of subjects earned greater than 40 hours (n = 20 or 57.1%). The second largest group of individuals earned between 35-40 hours (n = 8 or 22.9%). There was one individual that earned less than 20 hours during the first week (n = 1 or 2.9%). There were no

individuals who earned between 20-24 hours. The earned hours ranged from 7.1 to 53.3. Of the 41 individuals in the study, earned hours were obtained from 35 individuals during week one.

The results are presented in Table 7.

Table 7.

Earned Hours for Three Consecutive Weeks Before Introducing Three Dimensional Modeling of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Earned Hours	Week 1		Week 2		Week 3	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
< 20	1	2.9	6	16.2	15	38.5
20-24	0	0.0	3	8.1	9	23.1
25-29	2	5.7	7	18.9	7	17.9
30-34	4	11.4	7	18.9	6	15.4
35-40	8	22.9	10	27.0	2	5.1
> 40	20	57.1	4	10.9	0	0.0
Total	35 ^a	100.0	37 ^b	100.0	39 ^c	100.0

Note. Week 1 Mean earned hours = 40.0, SD = 9.27, Range = 7.1 – 53.3

Week 2 Mean earned hours = 29.2, SD = 9.63, Range = 5.9 – 42.0

Week 3 Mean earned hours = 22.8, SD = 7.37, Range = 5.6 – 40.0

^a6 of the individuals in the study did not have earned hours for week 1

^b4 of the individuals in the study did not have earned hours for week 2

^c2 of the individuals in the study did not have earned hours for week 3

The mean earned labor hours for week two of the study was 29.2 (SD = 9.63). During week two, the largest number of subjects earned between 35-40 hours (n = 10 or 27.0%). There were two groups of individuals who earned between 25-29 hours (n = 7 or 18.9%) and 30-34

hours ($\underline{n} = 7$ or 18.9%). The smallest group of subjects earned between 20-24 hours during week two ($\underline{n} = 3$ or 8.1%). The earned hours ranged from 5.9 to 42.0. Of the 41 individuals in the study, earned hours were obtained from 37 individuals during week two. The results are presented in Table 7.

The mean earned labor hours for week three of the study was 22.8 ($\underline{SD} = 7.37$). During week three, the largest number of subjects earned less than 20 hours ($\underline{n} = 15$ or 38.5%). The second largest group of individuals earned between 20-24 hours ($\underline{n} = 9$ or 23.1%). The smallest group of subjects earned between 35-40 hours during week three ($\underline{n} = 2$ or 5.1%). There were no individuals who earned greater than 40 hours. The earned hours ranged from 5.6 to 40.0. Of the 41 individuals in the study, earned hours were obtained from 39 individuals during week three. The results are presented in Table 7.

The mean labor productivity for week one of the study was 1.28 ($\underline{SD} = 0.115$). During week one, the largest number of subjects had labor productivity greater than 1.25 ($\underline{n} = 22$ or 62.9%). The smallest group of individuals had labor productivity between 1.0-1.25 ($\underline{n} = 13$ or 37.1%). There were no individuals who experienced labor productivity less than 0.25 or between 0.25-0.49, 0.50-0.74, and 0.75-0.99. The labor productivity ranged from 1.01 to 1.48. Of the 41 individuals in the study, labor productivity was obtained from 35 individuals during week one. The results are presented in Table 8.

The mean labor productivity for week two of the study was 0.78 ($\underline{SD} = 0.123$). During week two, the largest number of subjects had labor productivity between 0.75-0.99 ($\underline{n} = 21$ or 56.8%). The smallest group of individuals had labor productivity between 0.50-0.74 ($\underline{n} = 16$ or 43.2%). There were no individuals who experienced labor productivity less than 0.25, greater than 1.25, or between 0.25-0.49 and 1.0-1.25. The labor productivity ranged from 0.50 to 0.95.

Of the 41 individuals in the study, labor productivity was obtained from 37 individuals during week two. The results are presented in Table 8.

Table 8.
Labor Productivity for Three Consecutive Weeks Before Introducing Three Dimensional Modeling of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Labor Productivity	Week 1		Week 2		Week 3	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
< 0.25	0	0.0	0	0.0	0	0.0
0.25-0.49	0	0.0	0	0.0	24	61.5
0.50-0.74	0	0.0	16	43.2	15	38.5
0.75-0.99	0	0.0	21	56.8	0	0.0
1.0-1.25	13	37.1	0	0.0	0	0.0
> 1.25	22	62.9	0	0.0	0	0.0
Total	35 ^a	100.0	37 ^b	100.0	39 ^c	100.0

Note. Week 1 Mean labor productivity = 1.28, SD = 0.115, Range = 1.01 – 1.48

Week 2 Mean labor productivity = 0.78, SD = 0.123, Range = 0.50 – 0.95

Week 3 Mean labor productivity = 0.45, SD = 0.127, Range = 0.28 – 0.69

^a6 of the individuals in the study did not have labor productivity measures for week 1

^b4 of the individuals in the study did not have labor productivity measures for week 2

^c2 of the individuals in the study did not have labor productivity measures for week 3

The mean labor productivity for week three of the study was 0.45 (SD = 0.127). During week three, the largest number of subjects had labor productivity between 0.25-0.49 (n = 24 or 61.5%). The smallest group of individuals had labor productivity between 0.50-0.74 (n = 15 or 38.5%). There were no individuals who experienced labor productivity less than 0.25, greater

than 1.25, or between 0.75-0.99 and 1.0-1.25. The labor productivity ranged from 0.28 to 0.69. Of the 41 individuals in the study, labor productivity was obtained from 39 individuals during week three. The results are presented in Table 8.

The mean labor productivity of three consecutive weeks before introducing three dimensional modeling during the study was 0.73 (SD = 0.149). The largest number of subjects had mean labor productivity between 0.75-0.99 (n = 21 or 53.8%). The second largest group of individuals had mean labor productivity between 0.50-0.74 (n = 13 or 33.3%). There was one individual with mean labor productivity between 1.0-1.25 (n = 1 or 2.6%). There were no individuals with mean labor productivity less than 0.25 or greater than 1.25. The mean labor productivity ranged from 0.32 to 1.02. Of the 41 individuals in the study, mean labor productivity measures were obtained from 39 individuals during the first three weeks of the study. These mean labor productivity measures were the pretest scores. The results are presented in Table 9.

Objective Three: Results

The third objective of the study was to determine the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana on three consecutive weekly measures taken after introducing three dimensional modeling. These labor productivity measures were the posttest scores.

Out of the total group of 41 individuals in the study, this objective utilized data collected from 39 individuals that were associated with installing structural steel during the final three weeks of the study. The labor hours expended and earned for each of the 39 subjects were summarized using frequencies, percentages, ranges, means, and standard deviations. The labor productivity for each of the 39 subjects was calculated from the labor hours earned and expended according to the following calculation:

Labor productivity = earned labor hours / expended labor hours.

The labor productivity for each of the 39 subjects was summarized using frequencies, percentages, ranges, means, and standard deviations.

Table 9.

Mean Labor Productivity of Three Consecutive Weeks Before Introducing Three Dimensional Modeling of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Mean Labor Productivity	Frequency	Percent
< 0.25	0	0.0
0.25-0.49	4	10.3
0.50-0.74	13	33.3
0.75-0.99	21	53.8
1.0-1.25	1	2.6
> 1.25	0	0.0
Total	39 ^a	100.0

Note. Mean labor productivity = 0.73, SD = 0.149, Range = 0.32 – 1.02

^a2 of the individuals in the study were missing labor productivity measures for weeks 1-3

The mean expended labor hours for week four of the study was 45.1 (SD = 14.82). During week four, the largest number of subjects worked greater than 40 hours (n = 28 or 71.8%). The second largest group of individuals worked less than 20 hours (n = 4 or 10.3%). There was one individual that worked between 30-34 hours during the fourth week (n = 1 or

2.6%). The expended hours ranged from 7.0 to 59.2. Of the 41 individuals in the study, expended hours were obtained from 39 individuals during week four. The results are presented in Table 10.

Table 10.

Expended Hours for Three Consecutive Weeks After Introducing Three Dimensional Modeling of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Expended Hours	Week 4		Week 5		Week 6	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
< 20	4	10.3	3	7.9	5	13.5
20-24	2	5.1	1	2.6	0	0.0
25-29	2	5.1	2	5.3	2	5.4
30-34	1	2.6	0	0.0	2	5.4
35-40	2	5.1	3	7.9	25	67.6
> 40	28	71.8	29	76.3	3	8.1
Total	39 ^a	100.0	38 ^b	100.0	37 ^c	100.0

Note. Week 4 Mean expended hours = 45.1, SD = 14.82, Range = 7.0 – 59.2

Week 5 Mean expended hours = 46.2, SD = 13.79, Range = 8.0 – 62.8

Week 6 Mean expended hours = 34.6, SD = 9.53, Range = 4.2 – 41.1

^a2 of the individuals in the study did not have expended hours for week 4

^b3 of the individuals in the study did not have expended hours for week 5

^c4 of the individuals in the study did not have expended hours for week 6

The mean expended labor hours for week five of the study was 46.2 (SD = 13.79).

During week five, the largest number of subjects worked greater than 40 hours (n = 29 or

76.3%). There were two groups of individuals who worked less than 20 hours (n = 3 or 7.9%)

and between 35-40 hours (n = 3 or 7.9%). There was one individual that worked between 20-24

hours during the fifth week ($\underline{n} = 1$ or 2.6%). There were no individuals who worked between 30-34 hours. The expended hours ranged from 8.0 to 62.8. Of the 41 individuals in the study, expended hours were obtained from 38 individuals during week five. The results are presented in Table 10.

The mean expended labor hours for week six of the study was 34.6 ($\underline{SD} = 9.53$). During week six, the largest number of subjects worked between 35-40 hours ($\underline{n} = 25$ or 67.6%). The second largest group of individuals worked less than 20 hours ($\underline{n} = 5$ or 13.5%). There were no individuals who worked between 20-24 hours. The expended hours ranged from 4.2 to 41.1. Of the 41 individuals in the study, expended hours were obtained from 37 individuals during week six. The results are presented in Table 10.

The mean earned labor hours for week four of the study was 26.9 ($\underline{SD} = 11.62$). During week four, the largest number of subjects earned between 35-40 hours ($\underline{n} = 12$ or 30.8%). The second largest group of individuals earned less than 20 hours ($\underline{n} = 10$ or 25.7%). The smallest group of individuals earned greater than 40 hours during the fourth week ($\underline{n} = 2$ or 5.1%). The earned hours ranged from 2.8 to 49.0. Of the 41 individuals in the study, earned hours were obtained from 39 individuals during week four. The results are presented in Table 11.

The mean earned labor hours for week five of the study was 19.4 ($\underline{SD} = 6.91$). During week five, the largest number of subjects earned less than 20 hours ($\underline{n} = 19$ or 50.0%). The second largest group of individuals earned between 25-29 hours ($\underline{n} = 10$ or 26.3%). There was one individual that earned between 30-34 hours during the fifth week ($\underline{n} = 1$ or 2.6%). There were no individuals who earned between 35-40 hours and greater than 40 hours. The earned hours ranged from 2.8 to 30.8. Of the 41 individuals in the study, earned hours were obtained from 38 individuals during week five. The results are presented in Table 11.

Table 11.

Earned Hours for Three Consecutive Weeks After Introducing Three Dimensional Modeling of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Earned Hours	Week 4		Week 5		Week 6	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
< 20	10	25.7	19	50.0	5	13.5
20-24	5	12.8	8	21.1	2	5.4
25-29	5	12.8	10	26.3	8	21.6
30-34	5	12.8	1	2.6	6	16.2
35-40	12	30.8	0	0.0	15	40.6
> 40	2	5.1	0	0.0	1	2.7
Total	39 ^a	100.0	38 ^b	100.0	37 ^c	100.0

Note. Week 4 Mean earned hours = 26.9, SD = 11.62, Range = 2.8 – 49.0

Week 5 Mean earned hours = 19.4, SD = 6.91, Range = 2.8 – 30.8

Week 6 Mean earned hours = 29.8, SD = 9.12, Range = 3.0 – 41.3

^a2 of the individuals in the study did not have earned hours for week 4

^b3 of the individuals in the study did not have earned hours for week 5

^c4 of the individuals in the study did not have earned hours for week 6

The mean earned labor hours for week six of the study was 29.8 (SD = 9.12). During week six, the largest number of subjects earned between 35-40 hours (n = 15 or 40.6%). The second largest group of individuals earned between 25-29 hours (n = 8 or 21.6%). There was one individual that earned greater than 40 hours during the sixth week (n = 1 or 2.7%). The earned hours ranged from 3.0 to 41.3. Of the 41 individuals in the study, earned hours were obtained from 37 individuals during week six. The results are presented in Table 11.

The mean labor productivity for week four of the study was 0.58 (SD = 0.129). During week four, the largest number of subjects had labor productivity between 0.50-0.74 (n = 26 or 66.7%). The smallest group of individuals had labor productivity between 0.75-0.99 (n = 2 or 5.7%). There were no individuals who experienced labor productivity less than 0.25, greater than 1.25, or between 1.0-1.25. The labor productivity ranged from 0.29 to 0.86. Of the 41 individuals in the study, labor productivity was obtained from 39 individuals during week four. The results are presented in Table 12.

The mean labor productivity for week five of the study was 0.41 (SD = 0.061). During week five, the largest number of subjects had labor productivity between 0.25-0.49 (n = 34 or 89.5%). The smallest group of individuals had labor productivity between 0.50-0.74 (n = 4 or 10.5%). There were no individuals who experienced labor productivity less than 0.25, greater than 1.25, or between 0.75-0.99 and 1.0-1.25. The labor productivity ranged from 0.31 to 0.56. Of the 41 individuals in the study, labor productivity was obtained from 38 individuals during week five. The results are presented in Table 12.

The mean labor productivity for week six of the study was 0.86 (SD = 0.105). During week six, the largest number of subjects had labor productivity between 0.75-0.99 (n = 25 or 67.6%). The smallest group of individuals had labor productivity between 1.0-1.25 (n = 2 or 5.4%). There were no individuals who experienced labor productivity less than 0.25, greater than 1.25, or between 0.25-0.49. The labor productivity ranged from 0.69 to 1.06. Of the 41 individuals in the study, labor productivity was obtained from 37 individuals during week six. The results are presented in Table 12.

Table 12.

Labor Productivity for Three Consecutive Weeks After Introducing Three Dimensional Modeling of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Labor Productivity	Week 4		Week 5		Week 6	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
< 0.25	0	0.0	0	0.0	0	0.0
0.25-0.49	11	28.2	34	89.5	0	0.0
0.50-0.74	26	66.7	4	10.5	10	27.0
0.75-0.99	2	5.1	0	0.0	25	67.6
1.0-1.25	0	0.0	0	0.0	2	5.4
> 1.25	0	0.0	0	0.0	0	0.0
Total	39 ^a	100.0	38 ^b	100.0	37 ^c	100.0

Note. Week 4 Mean labor productivity = 0.58, SD = 0.129, Range = 0.29 – 0.86

Week 5 Mean labor productivity = 0.41, SD = 0.061, Range = 0.31 – 0.56

Week 6 Mean labor productivity = 0.86, SD = 0.105, Range = 0.69 – 1.06

^a2 of the individuals in the study did not have labor productivity measures for week 4

^b3 of the individuals in the study did not have labor productivity measures for week 5

^c4 of the individuals in the study did not have labor productivity measures for week 6

Objective Four: Results

The fourth objective of the study was to compare the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana before introducing three dimensional modeling with each of the three consecutive weekly measures taken after introducing three dimensional modeling.

The labor productivity measures or dependent variables were calculated based on an interval or higher scale of measurement. These variables were compared using the paired t-test procedure in the SPSS statistical software to determine if a difference existed in labor productivity before and after introducing three dimensional modeling. An a' priori significance level of .05 was used to determine if the dependent variables were significantly different. As a result, significant differences were found before and after introducing three dimensional modeling.

Productivity Week Four

There was a significant difference found between the labor productivity before introducing three dimensional modeling and the labor productivity after introducing three dimensional modeling during week four ($t = -6.233$, $p < .001$). The nature of the difference exists due to the labor productivity before introducing three dimensional modeling ($\underline{M} = 0.73$, $\underline{SD} = 0.150$) having a significantly higher productivity measure than the labor productivity after introducing three dimensional modeling during week four ($\underline{M} = 0.58$, $\underline{SD} = 0.131$). Table 13 presents the productivity week four data.

Productivity Week Five

The comparison with the greatest difference was found between the labor productivity before introducing three dimensional modeling and the labor productivity after introducing three dimensional modeling during week five ($t = -13.236$, $p < .001$). The nature of the difference exists due to the labor productivity before introducing three dimensional modeling ($\underline{M} = 0.75$, $\underline{SD} = 0.140$) having a significantly higher productivity measure than the labor productivity after introducing three dimensional modeling during week five ($\underline{M} = 0.41$, $\underline{SD} = 0.062$). The productivity week five data is presented in Table 13.

Productivity Week Six

There was a significant difference found between the labor productivity before introducing three dimensional modeling and the labor productivity after introducing three dimensional modeling during week six ($t = 3.517$, $p = .001$). The nature of the difference exists due to the labor productivity before introducing three dimensional modeling ($M = 0.75$, $SD = 0.142$) having a significantly lower productivity measure than the labor productivity after introducing three dimensional modeling during week six ($M = 0.86$, $SD = 0.106$). Table 13 presents the productivity week six data.

Table 13.

Comparison of Labor Productivity Before Introducing Three Dimensional Modeling With Each of the Three Consecutive Weekly Measures Taken After Introducing Three Dimensional Modeling of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Variable	<u>N</u>	<u>M</u>	<u>SD</u>	<u>t</u>	df	<u>p</u>
Productivity Week 4						
Before 3D Modeling	38	0.73	0.150			
After 3D Modeling	38	0.58	0.131	-6.233	37	< .001
Productivity Week 5						
Before 3D Modeling	36	0.75	0.140			
After 3D Modeling	36	0.41	0.062	-13.236	35	< .001
Productivity Week 6						
Before 3D Modeling	35	0.75	0.142			
After 3D Modeling	35	0.86	0.106	3.517	34	.001

Objective Five: Results

The fifth objective of the study was to determine if a model exists explaining a significant portion of the variance in the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana before

introducing three dimensional modeling from the following selected personal and professional demographic characteristics:

- i. age
- ii. gender
- iii. total years of construction experience
- iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc).

The data collected was analyzed using multiple regression analysis in the SPSS statistical software. The dependent variable was the mean labor productivity scores of three consecutive weeks before introducing three dimensional modeling. The independent variables were age, total years of construction experience, and worker classification. Since all subjects were male, gender was a constant and therefore not included in the multiple regression analysis. The variables were entered into the analysis using stepwise entry procedures due to the exploratory nature of the study.

Since the variables age and total years of construction experience were interval in nature, they did not require recoding. These variables were entered into the analysis. However, since the variable worker classification was categorical in nature, it had to be recoded as a dichotomous variable.

The variable worker classification had seven nominal categories: “Mechanic A”, “Foreman”, “Helper I”, “Helper III”, “Mechanic B”, “Mechanic C”, and “General Foreman”. Six of these categories had inadequate frequencies for use in the analysis. These categories included “Foreman” ($\underline{n} = 4$), “Helper I” ($\underline{n} = 4$), “Helper III” ($\underline{n} = 1$), “Mechanic B” ($\underline{n} = 1$), “Mechanic C” ($\underline{n} = 1$), and “General Foreman” ($\underline{n} = 1$). As a result of the inadequate frequencies, these categories were removed before the variable worker classification was entered into the analysis.

Therefore subjects were classified as “Mechanic A” or not “Mechanic A” and this single category was used to create a dichotomous variable as being a member of this category or not. With this recoding, the variable worker classification was entered into the analysis.

Before performing multiple regression analysis, the bivariate correlations between the dependent and independent variables were examined. The bivariate correlations between the mean labor productivity scores of three consecutive weeks before introducing three dimensional modeling and age, total years of construction experience, and worker classification are presented in Table 14.

The mean labor productivity scores of three consecutive weeks before introducing three dimensional modeling was 0.75 (SD = 0.141). The highest correlation with the mean labor productivity scores of three consecutive weeks before introducing three dimensional modeling was found to be with the variable worker classification ($r = .16$, $p = .177$). The lowest correlation with the mean labor productivity scores of three consecutive weeks before introducing three dimensional modeling was found to be with the variable total years of construction experience ($r = -.08$, $p = .315$).

However, none of the correlations were found to be statistically significant and consequently none of the independent variables age, total years of construction experience, and worker classification entered the multiple regression model. Therefore, no model existed explaining a significant portion of the variance in structural steel installation labor productivity before introducing three dimensional modeling from the variables age, total years of construction experience, and worker classification.

Table 14.

Relationship Between Selected Personal and Professional Demographic Characteristics and Mean Labor Productivity Scores of Three Consecutive Weeks Before Introducing Three Dimensional Modeling of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Variable	r	p
Worker Classification	.16	.177
Age	-.10	.276
Total Years of Construction Experience	-.08	.315

Note. $n = 35$; Mean labor productivity scores of three consecutive weeks before introducing three dimensional modeling = 0.75 ($SD = 0.141$)

Objective Six: Results

The last objective of the study was to determine if a model exists explaining a significant portion of the variance in the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana for each of the three weeks after introducing three dimensional modeling from the following selected personal and professional demographic characteristics:

- i. age
- ii. gender
- iii. total years of construction experience
- iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc)
- v. frequency of looking at the three dimensional model shots.

The data collected was analyzed using multiple regression analysis in the SPSS statistical software. The dependent variable was each week's mean labor productivity scores after introducing three dimensional modeling. The independent variables were age, total years of construction experience, worker classification, and frequency of looking at the three dimensional model shots. The variable perceived helpfulness of the three dimensional model shots was omitted from the regression analysis due to a high correlation with the variable frequency of looking at the three dimensional model shots. Since all subjects were male, gender was a constant and therefore not included in the regression analysis. The variables were entered into the analysis using stepwise entry procedures due to the exploratory nature of the study.

Since the variables age, total years of construction experience, and frequency of looking at the three dimensional model shots were interval in nature, they did not require recoding. These variables were entered into the analysis. However, since the variable worker classification was categorical in nature, it had to be recoded as a dichotomous variable.

The variable worker classification had seven nominal categories: "Mechanic A", "Foreman", "Helper I", "Helper III", "Mechanic B", "Mechanic C", and "General Foreman". Six of these categories had inadequate frequencies for use in the analysis. These categories included "Foreman" ($\underline{n} = 4$), "Helper I" ($\underline{n} = 4$), "Helper III" ($\underline{n} = 1$), "Mechanic B" ($\underline{n} = 1$), "Mechanic C" ($\underline{n} = 1$), and "General Foreman" ($\underline{n} = 1$). As a result of the inadequate frequencies, these categories were removed before the variable worker classification was entered into the analysis. Therefore subjects were classified as "Mechanic A" or not "Mechanic A" and this single category was used to create a dichotomous variable as being a member of this category or not. With this recoding, the variable worker classification was entered into the analysis.

Before performing multiple regression analysis, the bivariate correlations between the dependent and independent variables were examined. The bivariate correlations between the mean labor productivity scores of week four and age, total years of construction experience, worker classification, and frequency of looking at the three dimensional model shots are presented in Table 15.

Table 15.
Relationship Between Selected Personal and Professional Demographic Characteristics and Mean Labor Productivity Scores of Week Four After Introducing Three Dimensional Modeling of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Variable	r	p
Age	-.18	.145
Total Years of Construction Experience	-.17	.168
Frequency of Looking at the Three Dimensional Model Shots	-.11	.266
Worker Classification	-.06	.363

Note. $n = 35$; Mean labor productivity scores of week four after introducing three dimensional modeling = 0.60, $SD = 0.109$

The mean labor productivity scores of week four after introducing three dimensional modeling was 0.60 ($SD = 0.109$). The highest correlation with the mean labor productivity scores of week four after introducing three dimensional modeling was found to be with the variable age ($r = -.18$, $p = .145$). The lowest correlation with the mean labor productivity scores of week four after introducing three dimensional modeling was found to be with the variable worker classification ($r = -.06$, $p = .363$). However, none of the correlations were found to be statistically

significant. Therefore, none of the independent variables included in the analysis (age, total years of construction experience, worker classification, and frequency of looking at the three dimensional model shots) were entered into the multiple regression model.

The bivariate correlations between the mean labor productivity scores of week five and age, total years of construction experience, worker classification, and frequency of looking at the three dimensional model shots are presented in Table 16.

Table 16.
Relationship Between Selected Personal and Professional Demographic Characteristics and Mean Labor Productivity Scores of Week Five After Introducing Three Dimensional Modeling of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Variable	r	p
Frequency of Looking at the Three Dimensional Model Shots	.15	.199
Total Years of Construction Experience	-.14	.208
Worker Classification	.06	.370
Age	-.03	.436

Note. $n = 36$; Mean labor productivity scores of week five after introducing three dimensional modeling = 0.42, $SD = 0.062$

The mean labor productivity scores of week five after introducing three dimensional modeling was 0.42 ($SD = 0.062$). The highest correlation with the mean labor productivity scores of week five after introducing three dimensional modeling was found to be with the variable frequency of looking at the three dimensional model shots ($r = .15$, $p = .199$). The lowest correlation with the mean labor productivity scores of week five after introducing three

dimensional modeling was found to be with the variable age ($r = -.03$, $p = .436$). However, none of the correlations were found to be statistically significant. Therefore, none of the independent variables included in the analysis (age, total years of construction experience, worker classification, and frequency of looking at the three dimensional model shots) were entered into the multiple regression model.

The bivariate correlations between the mean labor productivity scores of week six and age, total years of construction experience, worker classification, and frequency of looking at the three dimensional model shots are presented in Table 17.

Table 17.
Relationship Between Selected Personal and Professional Demographic Characteristics and Mean Labor Productivity Scores of Week Six After Introducing Three Dimensional Modeling of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Variable	r	p
Frequency of Looking at the Three Dimensional Model Shots	.34	.023
Total Years of Construction Experience	.02	.446
Worker Classification	.02	.454
Age	-.02	.450

Note. $n = 35$; Mean labor productivity scores of week six after introducing three dimensional modeling = 0.86, $SD = 0.103$

The mean labor productivity scores of week six after introducing three dimensional modeling was 0.86 ($SD = 0.103$). The highest correlation with the mean labor productivity scores of week six after introducing three dimensional modeling was found to be with the variable

frequency of looking at the three dimensional model shots ($r = .34$, $p = .023$). The lowest correlations with the mean labor productivity scores of week six after introducing three dimensional modeling were found to be with the variables age ($r = -.02$, $p = .450$), total years of construction experience ($r = .02$, $p = .446$), and worker classification ($r = .02$, $p = .454$). Only the variable frequency of looking at the three dimensional model shots was found to be statistically significant. Therefore, the independent variables age, total years of construction experience, and worker classification did not enter into the multiple regression model. The variable frequency of looking at the three dimensional model shots did enter into the multiple regression model.

To ensure that variables entered into the multiple regression analysis did not have excessive collinearity or that any combination of the independent variables formed a singularity, the variance inflation factor (VIF) was examined. According to Hair et al. (2006), “A common cutoff threshold is a tolerance value of .10 which corresponds to a VIF value of 10” (p.230). The variance inflation factor values for this analysis ranged from 1.000 to 1.071. Therefore, no excess multicollinearity was present in the data.

The results of the multiple regression analysis utilizing the mean labor productivity scores of week six after introducing three dimensional modeling as the dependent variable are presented in Table 18.

The only variable that entered the model was frequency of looking at the three dimensional model shots. This variable explained 11.5% of the variance in mean labor productivity scores of week six after introducing three dimensional modeling of industrial construction workers installing structural steel in a selected industrial facility in southeastern Louisiana. This indicates that workers who reported that they looked at the three dimensional model shots more frequently tended to have higher labor productivity scores.

Table 18.

Multiple Regression Analysis of Mean Labor Productivity Scores of Week Six After Introducing Three Dimensional Modeling and Selected Personal and Professional Demographic Characteristics of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

ANOVA					
Source of Variation	df	MS	F	p	
Regression	1	.041	4.273	.047	
Residual	33	.010			
Total	34				
Model Summary					
Model	R Square	R Square Change	F Change	Sig. F Change	Standardized Coefficients Beta
Frequency of Looking at the Three Dimensional Model Shots	.115	.115	4.273	.047	.339
Variables not in the Equation					
Variable	t		p		
Age	-.102		.919		
Total Years of Construction Experience	.092		.927		
Worker Classification	.676		.504		

To further examine the impact of the selected factors on productivity, the time series measurements were treated as separate samples and all of the variables (including week of data collection, an interaction term between use of 3D model shots and the perceived helpfulness of 3D model shots, and an interaction term between use of 3D model shots and the frequency of looking at the 3D model shots) were entered into the regression analysis as independent variables. A total labor productivity score was computed for all six weeks and this measure was used as the dependent variable in this analysis. However, when this analysis was conducted a multicollinearity problem was encountered. Examination of this collinearity problem led the researcher to conclude that the most effective course of action was to eliminate the use of 3D model shots as an independent variable. This enabled the researcher to keep all of the remaining variables in the analysis including both interaction terms.

The bivariate correlations between the total labor productivity scores and age, total years of construction experience, worker classification, frequency of looking at the 3D model shots, perceived helpfulness of 3D model shots, interaction term between use of 3D model shots and the perceived helpfulness of 3D model shots, interaction term between use of 3D model shots and the frequency of looking at the 3D model shots, week two, week three, week five, and week six are presented in Table 19.

Table 19.
Relationship Between Selected Independent Variables and Total Labor Productivity Scores of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

Variable	r	p
Perceived Helpfulness of 3D Model Shots	-.36	< .001

(Table 19 continued)

Variable	r	p
Age	-.19	.002
Total Years of Construction Experience	-.15	.013
Interaction Term Between Use of 3D Model Shots and the Perceived Helpfulness of 3D Model Shots	-.14	.023
Worker Classification	.01	.427
Frequency of Looking at the 3D Model Shots	-.01	.478
Interaction Term Between Use of 3D Model Shots and the Frequency of Looking at the 3D Model Shots	-.01	.492
Week Two	.00	.500
Week Three	.00	.500
Week Five	.00	.500
Week Six	.00	.500

Note. $n = 216$; Mean total productivity scores = 0.72, $SD = 0.069$

The mean total labor productivity scores was 0.72 ($SD = 0.069$). The highest correlation with the mean total labor productivity scores was found to be with the variable perceived helpfulness of 3D model shots ($r = -.36$, $p < .001$). The lowest correlations with the mean total labor productivity scores were found to be with the variables week two, week three, week five, and week six ($r = .00$, $p = .500$).

The results of the multiple regression analysis utilizing the mean total labor productivity scores as the dependent variable are presented in Table 20. A significant model was found.

Table 20.
Multiple Regression Analysis of Total Labor Productivity Scores and Selected Independent Variables of Industrial Construction Workers That Were Working on a Project in a Selected Industrial Facility in Southeastern Louisiana

ANOVA				
Source of Variation	<u>df</u>	MS	F	p
Regression	11	.025	6.954	< .001
Residual	204	.004		
Total	215			
Model Summary				
Model	R Square	R Square Change	F Change	Sig. F Change
Perceived Helpfulness of 3D Model Shots	.273	.273	6.954	< .001
Age				
Total Years of Construction Experience				
Interaction Term Between Use of 3D Model Shots and the Perceived Helpfulness of 3D Model Shots				
Worker Classification				

(Table 20 continued)

Model Summary				
Model	R Square	R Square Change	F Change	Sig. F Change
Frequency of Looking at the 3D Model Shots				
Interaction Term Between Use of 3D Model Shots and the Frequency of Looking at the 3D Model Shots				
Week Two				
Week Three				
Week Five				
Week Six				
Individual Factor Contributions				
Variable	Standardized Coefficients Beta	t	p	
Perceived Helpfulness of 3D Model Shots	-.596	-6.013	< .001	
Frequency of Looking at the 3D Model Shots	.308	3.160	.002	
Age	-.268	-2.371	.019	
Total Years of Construction Experience	-.047	-.418	.677	
Worker Classification	-.003	-.045	.964	

(Table 20 continued)

Individual Factor Contributions			
Variable	Standardized Coefficients Beta	t	p
Interaction Term Between Use of 3D Model Shots and the Perceived Helpfulness of 3D Model Shots	.000	.000	1.000
Interaction Term Between Use of 3D Model Shots and the Frequency of Looking at the 3D Model Shots	.000	.000	1.000
Week Two	.000	.000	1.000
Week Three	.000	.000	1.000
Week Five	.000	.000	1.000
Week Six	.000	.000	1.000

The independent variables in the regression model were entered together as a full model and explained 27.3% of the variance in mean total labor productivity scores of industrial construction workers installing structural steel in a selected industrial facility in southeastern Louisiana. Examination of the Standardized Coefficients Beta reveals that three of the independent variables made a statistically significant contribution to the model. The interpretation of the impact of these variables suggests that as the perceived helpfulness of 3D model shots and age increases the labor productivity decreases and as the frequency of looking at the 3D model shots increases labor productivity increases.

CHAPTER 5: SUMMARY, CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS

Summary of Purpose and Specific Objectives

The primary purpose of this study was to determine if the use of three dimensional modeling to enhance visualization of structural steel installation would increase labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana. Specifically, this research addressed the following objectives:

1. Describe industrial construction workers that were working on a project in a selected industrial facility in southeastern Louisiana on the following selected personal and professional demographic characteristics:
 - i. age
 - ii. gender
 - iii. total years of construction experience
 - iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc)
 - v. frequency of looking at the three dimensional model shots
 - vi. perceived helpfulness of the three dimensional model shots.
2. Determine the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana on three consecutive weekly measures taken before introducing three dimensional modeling.
3. Determine the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana on three consecutive weekly measures taken after introducing three dimensional modeling.
4. Compare the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana before introducing

- three dimensional modeling with each of the three consecutive weekly measures taken after introducing three dimensional modeling.
5. Determine if a model exists explaining a significant portion of the variance in the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana before introducing three dimensional modeling from the following selected personal and professional demographic characteristics:
 - i. age
 - ii. gender
 - iii. total years of construction experience
 - iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc).
 6. Determine if a model exists explaining a significant portion of the variance in the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana for each of the three weeks after introducing three dimensional modeling from the following selected personal and professional demographic characteristics:
 - i. age
 - ii. gender
 - iii. total years of construction experience
 - iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc)
 - v. frequency of looking at the three dimensional model shots.

Summary of Methodology

This researcher utilized a one-group pretest-posttest time series design. Since the timing of this experiment coincided with an ongoing industrial construction project, the individuals in

the study were previously assigned to the project therefore no random sampling was possible. Dependent variable measurements were taken multiple times on each subject and the subjects acted as their own control.

The target population was industrial construction workers in the southeastern region of the United States. This researcher's accessible group was industrial construction workers installing structural steel during the time of this study at a selected southeastern Louisiana chemical plant facility. This accessible group consisted of 41 individuals.

The instrument used to collect the labor hours expended and the worker classification was the company's timesheet. The instrument used to collect the labor hours earned was the company's progress reporting system. This reporting system calculated the labor hours earned from the completion percentage and the estimated hours for a particular work item for the work crews. Based on the progress reports, this researcher used foreman daily work tickets, interviews with the general foreman, and field observations to determine individual earned hours.

The instrument used to collect the total years of construction experience, frequency of looking at the three dimensional model shots, and perceived helpfulness of the three dimensional model shots was a posttest survey.

After approval from the Louisiana State University Institution Review Board and dissertation advisory committee, this researcher proceeded with the study. During the initial three weeks of the study, timesheets and progress reports indicating labor hours expended and earned for the workers in the experiment were received weekly from the timekeeper and planner. This researcher determined individual earned hours from the progress reports. In addition, this researcher calculated productivity measures for each week based on this information using the following formula:

$$\text{Labor productivity} = \text{Earned labor hours} / \text{Expended labor hours}.$$

These weekly measures represented pretest scores.

After the initial three weeks, this researcher generated and provided letter size color 3D model shots of the particular steel members being installed to the general foreman in order to share with each foreman and the steel workers in the study. The steel workers utilized the 3D model shots during the installation process for a three week period. During these three weeks, timesheets and progress reports indicating labor hours expended and earned for the workers in the experiment were received weekly from the timekeeper and planner. This researcher determined individual earned hours from the progress reports. In addition, this researcher calculated productivity measures for each week based on this information. These weekly measures represented posttest scores.

After receiving the company's timesheets, the worker classification for each individual was determined. In addition, a posttest survey was administered and the total years of construction experience, frequency of looking at the three dimensional model shots, and perceived helpfulness of the three dimensional model shots were obtained. The age and gender of each individual in the study were provided by the company.

Summary of Findings

Objective One

The first objective of the study was to describe industrial construction workers that were working on a project in a selected industrial facility in southeastern Louisiana on the following selected personal and professional demographic characteristics:

- i. age
- ii. gender

- iii. total years of construction experience
- iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc)
- v. frequency of looking at the three dimensional model shots
- vi. perceived helpfulness of the three dimensional model shots.

The variables age, total years of construction experience, frequency of looking at the three dimensional model shots, perceived helpfulness of the three dimensional model were interval variables and were summarized using frequencies, percentages, means, and standard deviations. The variables gender and worker classification were nominal variables and were summarized using frequencies and percentages.

The mean age in years of the 41 individuals in the study was 35.4 ($SD = 10.67$). The largest number of subjects were in the “21-30” year age group ($n = 18$ or 43.9%). There were no individuals under the age of 21 or over the age of 60. All individuals in the study were male ($n = 41$, 100%).

The mean total years of construction experience was 12.4 ($SD = 8.45$). The largest number of subjects were in the “6-10” year construction experience group ($n = 20$ or 55.6%). The total years of construction experience ranged from 1 to 35. Of the 41 individuals being described, only data from 36 individuals related to total years of construction experience were obtained.

The worker classifications related to the 41 individuals in the study were obtained. The majority of the subjects were classified as “Mechanic A” ($n = 29$ or 70.7%).

The mean frequency of looking at the three dimensional model shots was 2.5 ($SD = 1.09$). Data on this variable was gathered by asking the individuals in the study: “How often did you look at the 3D model shots (computer pictures)?” on a posttest survey. The majority of the

subjects indicated that they looked at the three dimensional model shots either “occasionally”, “several times”, or “many times” ($\underline{n} = 20$ or 57.1%). The largest number of subjects indicated that they “occasionally” looked at the three dimensional model shots ($\underline{n} = 14$ or 40.0%). Only data from 35 individuals was received for this variable.

The mean perceived helpfulness of the three dimensional model shots was 2.8 ($\underline{SD} = 1.26$). Data on this variable was gathered by asking the individuals in the study: “How helpful did you find the 3D model shots?” on a posttest survey. The majority of the subjects indicated that the three dimensional model shots were either “fairly helpful”, “helpful”, or “very helpful” ($\underline{n} = 20$ or 57.1%). The largest number of subjects indicated that the three dimensional model shots were “helpful” ($\underline{n} = 11$ or 31.4%). Only data from 35 individuals was received for this variable.

Objective Two

The second objective of the study was to determine the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana on three consecutive weekly measures taken before introducing three dimensional modeling.

Out of the total group of 41 individuals in the study, this objective utilized data collected from 39 individuals that were associated with installing structural steel during the first three weeks of the study. In addition to the labor hours expended and earned, the calculated labor productivity for each of the 39 subjects were summarized using frequencies, percentages, ranges, means, and standard deviations.

The mean expended labor hours for week one of the study was 31.3 ($\underline{SD} = 6.71$). During week one, the largest number of subjects worked between 35-40 hours ($\underline{n} = 17$ or 48.5%). There

were no individuals who worked greater than 40 hours. The expended hours ranged from 5.0 to 37.0.

The mean expended labor hours for week two of the study was 37.5 (SD = 10.40). During week two, the largest number of subjects worked greater than 40 hours (n = 21 or 56.8%). The expended hours ranged from 9.0 to 44.5.

The mean expended labor hours for week three of the study was 50.7 (SD = 9.07). During week three, the largest number of subjects worked greater than 40 hours (n = 36 or 92.2%). The expended hours ranged from 17.6 to 58.0.

The mean earned labor hours for week one of the study was 40.0 (SD = 9.27). During week one, the largest number of subjects earned greater than 40 hours (n = 20 or 57.1%). The earned hours ranged from 7.1 to 53.3.

The mean earned labor hours for week two of the study was 29.2 (SD = 9.63). During week two, the largest number of subjects earned between 35-40 hours (n = 10 or 27.0%). There were two groups of individuals who earned between 25-29 hours (n = 7 or 18.9%) and 30-34 hours (n = 7 or 18.9%). The earned hours ranged from 5.9 to 42.0.

The mean earned labor hours for week three of the study was 22.8 (SD = 7.37). During week three, the largest number of subjects earned less than 20 hours (n = 15 or 38.5%). The second largest group of individuals earned between 20-24 hours (n = 9 or 23.1%). The earned hours ranged from 5.6 to 40.0.

The mean labor productivity for week one of the study was 1.28 (SD = 0.115). During week one, the largest number of subjects had labor productivity greater than 1.25 (n = 22 or 62.9%). The smallest group of individuals had labor productivity between 1.0-1.25 (n = 13 or 37.1%). The labor productivity ranged from 1.01 to 1.48.

The mean labor productivity for week two of the study was 0.78 (SD = 0.123). During week two, the largest number of subjects had labor productivity between 0.75-0.99 (n = 21 or 56.8%). The smallest group of individuals had labor productivity between 0.50-0.74 (n = 16 or 43.2%). The labor productivity ranged from 0.50 to 0.95.

The mean labor productivity for week three of the study was 0.45 (SD = 0.127). During week three, the largest number of subjects had labor productivity between 0.25-0.49 (n = 24 or 61.5%). The smallest group of individuals had labor productivity between 0.50-0.74 (n = 15 or 38.5%). The labor productivity ranged from 0.28 to 0.69.

The mean labor productivity of three consecutive weeks before introducing three dimensional modeling during the study was 0.73 (SD = 0.149). The largest number of subjects had mean labor productivity between 0.75-0.99 (n = 21 or 53.8%). The second largest group of individuals had mean labor productivity between 0.50-0.74 (n = 13 or 33.3%). The mean labor productivity ranged from 0.32 to 1.02. These mean labor productivity measures were the pretest scores.

Objective Three

The third objective of the study was to determine the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana on three consecutive weekly measures taken after introducing three dimensional modeling.

Out of the total group of 41 individuals in the study, this objective utilized data collected from 39 individuals that were associated with installing structural steel during the final three weeks of the study. In addition to the labor hours expended and earned, the calculated labor productivity for each of the 39 subjects were summarized using frequencies, percentages, ranges, means, and standard deviations.

The mean expended labor hours for week four of the study was 45.1 ($\underline{SD} = 14.82$). During week four, the largest number of subjects worked greater than 40 hours ($\underline{n} = 28$ or 71.8%). The expended hours ranged from 7.0 to 59.2.

The mean expended labor hours for week five of the study was 46.2 ($\underline{SD} = 13.79$). During week five, the largest number of subjects worked greater than 40 hours ($\underline{n} = 29$ or 76.3%). The expended hours ranged from 8.0 to 62.8.

The mean expended labor hours for week six of the study was 34.6 ($\underline{SD} = 9.53$). During week six, the largest number of subjects worked between 35-40 hours ($\underline{n} = 25$ or 67.6%). The expended hours ranged from 4.2 to 41.1.

The mean earned labor hours for week four of the study was 26.9 ($\underline{SD} = 11.62$). During week four, the largest number of subjects earned between 35-40 hours ($\underline{n} = 12$ or 30.8%). The smallest group of individuals earned greater than 40 hours during the fourth week ($\underline{n} = 2$ or 5.1%). The earned hours ranged from 2.8 to 49.0.

The mean earned labor hours for week five of the study was 19.4 ($\underline{SD} = 6.91$). During week five, the largest number of subjects earned less than 20 hours ($\underline{n} = 19$ or 50.0%). There was one individual that earned between 30-34 hours during the fifth week ($\underline{n} = 1$ or 2.6%). The earned hours ranged from 2.8 to 30.8.

The mean earned labor hours for week six of the study was 29.8 ($\underline{SD} = 9.12$). During week six, the largest number of subjects earned between 35-40 hours ($\underline{n} = 15$ or 40.6%). There was one individual that earned greater than 40 hours during the sixth week ($\underline{n} = 1$ or 2.7%). The earned hours ranged from 3.0 to 41.3.

The mean labor productivity for week four of the study was 0.58 ($\underline{SD} = 0.129$). During week four, the largest number of subjects had labor productivity between 0.50-0.74 ($\underline{n} = 26$ or

66.7%). The smallest group of individuals had labor productivity between 0.75-0.99 ($\underline{n} = 2$ or 5.7%). The labor productivity ranged from 0.29 to 0.86.

The mean labor productivity for week five of the study was 0.41 ($\underline{SD} = 0.061$). During week five, the largest number of subjects had labor productivity between 0.25-0.49 ($\underline{n} = 34$ or 89.5%). The smallest group of individuals had labor productivity between 0.50-0.74 ($\underline{n} = 4$ or 10.5%). The labor productivity ranged from 0.31 to 0.56.

The mean labor productivity for week six of the study was 0.86 ($\underline{SD} = 0.105$). During week six, the largest number of subjects had labor productivity between 0.75-0.99 ($\underline{n} = 25$ or 67.6%). The smallest group of individuals had labor productivity between 1.0-1.25 ($\underline{n} = 2$ or 5.4%). The labor productivity ranged from 0.69 to 1.06.

Objective Four

The fourth objective of the study was to compare the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana before introducing three dimensional modeling with each of the three consecutive weekly measures taken after introducing three dimensional modeling.

Variables were compared using the paired t-test procedure in the SPSS statistical software to determine if a difference existed in labor productivity before and after introducing three dimensional modeling. An a' priori significance level of .05 was used to determine if the dependent variables were significantly different.

There was a significant difference found between the labor productivity before introducing three dimensional modeling and the labor productivity after introducing three dimensional modeling during week four ($\underline{t} = -6.233$, $\underline{p} < .001$). The nature of the difference exists due to the labor productivity before introducing three dimensional modeling ($\underline{M} = 0.73$, $\underline{SD} =$

0.150) having a significantly higher productivity measure than the labor productivity after introducing three dimensional modeling during week four ($\underline{M} = 0.58$, $\underline{SD} = 0.131$).

The comparison with the greatest difference was found between the labor productivity before introducing three dimensional modeling and the labor productivity after introducing three dimensional modeling during week five ($t = -13.236$, $p < .001$). The nature of the difference exists due to the labor productivity before introducing three dimensional modeling ($\underline{M} = 0.75$, $\underline{SD} = 0.140$) having a significantly higher productivity measure than the labor productivity after introducing three dimensional modeling during week five ($\underline{M} = 0.41$, $\underline{SD} = 0.062$).

There was a significant difference found between the labor productivity before introducing three dimensional modeling and the labor productivity after introducing three dimensional modeling during week six ($t = 3.517$, $p = .001$). The nature of the difference exists due to the labor productivity before introducing three dimensional modeling ($\underline{M} = 0.75$, $\underline{SD} = 0.142$) having a significantly lower productivity measure than the labor productivity after introducing three dimensional modeling during week six ($\underline{M} = 0.86$, $\underline{SD} = 0.106$).

Objective Five

The fifth objective of the study was to determine if a model exists explaining a significant portion of the variance in the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana before introducing three dimensional modeling from the following selected personal and professional demographic characteristics:

- i. age
- ii. gender
- iii. total years of construction experience
- iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc).

The data collected was analyzed using multiple regression analysis. The dependent variable was the mean labor productivity scores of three consecutive weeks before introducing three dimensional modeling. The independent variables were age, total years of construction experience, and worker classification. Since all subjects were male, gender was a constant and therefore not included in the multiple regression analysis. The variables were entered into the analysis using stepwise entry procedures due to the exploratory nature of the study.

Since the variables age and total years of construction experience were interval in nature, they did not require recoding. These variables were entered into the analysis. However, since the variable worker classification was categorical in nature, it had to be recoded as a dichotomous variable. The variable worker classification had seven nominal categories. Six of these categories had inadequate frequencies and excluded from the analysis. Therefore subjects were classified as “Mechanic A” or not “Mechanic A” and this single category was used to create a dichotomous variable as being a member of this category or not. With this recoding, the variable worker classification was entered into the analysis.

Before performing multiple regression analysis, the bivariate correlations between the dependent and independent variables were examined. The mean labor productivity scores of three consecutive weeks before introducing three dimensional modeling was 0.75 (SD = 0.141). The highest correlation with the mean labor productivity scores of three consecutive weeks before introducing three dimensional modeling was found to be with the variable worker classification ($r = .16$, $p = .177$). The lowest correlation with the mean labor productivity scores of three consecutive weeks before introducing three dimensional modeling was found to be with the variable total years of construction experience ($r = -.08$, $p = .315$).

However, none of the correlations were found to be statistically significant and consequently none of the independent variables age, total years of construction experience, and worker classification entered the multiple regression model. Therefore, no model existed explaining a significant portion of the variance in structural steel installation labor productivity before introducing three dimensional modeling from the variables age, total years of construction experience, and worker classification.

Objective Six

The last objective of the study was to determine if a model exists explaining a significant portion of the variance in the structural steel installation labor productivity of industrial construction workers in a selected industrial facility in southeastern Louisiana for each of the three weeks after introducing three dimensional modeling from the following selected personal and professional demographic characteristics:

- i. age
- ii. gender
- iii. total years of construction experience
- iv. worker classification (Mechanic A, B, C ; Helper I, II, III ; etc)
- v. frequency of looking at the three dimensional model shots.

The data collected was analyzed using multiple regression analysis. The dependent variable was each week's mean labor productivity scores after introducing three dimensional modeling. The independent variables were age, total years of construction experience, worker classification, and frequency of looking at the three dimensional model shots. Since all subjects were male, gender was a constant and therefore not included in the multiple regression analysis.

The variables were entered into the analysis using stepwise entry procedures due to the exploratory nature of the study.

Since the variables age, total years of construction experience, and frequency of looking at the three dimensional model shots were interval in nature, they did not require recoding. These variables were entered into the analysis. However, since the variable worker classification was categorical in nature, it had to be recoded as a dichotomous variable. The variable worker classification had seven nominal categories. Six of these categories had inadequate frequencies and excluded from the analysis. Therefore subjects were classified as “Mechanic A” or not “Mechanic A” and this single category was used to create a dichotomous variable as being a member of this category or not. With this recoding, the variable worker classification was entered into the analysis.

Before performing multiple regression analysis, the bivariate correlations between the dependent and independent variables were examined. The mean labor productivity scores of week four after introducing three dimensional modeling was 0.60 ($SD = 0.109$). The highest correlation with the mean labor productivity scores of week four after introducing three dimensional modeling was found to be with the variable age ($r = -.18$, $p = .145$). The lowest correlation with the mean labor productivity scores of week four after introducing three dimensional modeling was found to be with the variable worker classification ($r = -.06$, $p = .363$). However, none of the correlations were found to be statistically significant. Therefore, none of the independent variables included in the analysis (age, total years of construction experience, worker classification, and frequency of looking at the three dimensional model shots) were entered into the multiple regression model.

The mean labor productivity scores of week five after introducing three dimensional modeling was 0.42 (SD = 0.062). The highest correlation with the mean labor productivity scores of week five after introducing three dimensional modeling was found to be with the variable frequency of looking at the three dimensional model shots ($r = .15$, $p = .199$). The lowest correlation with the mean labor productivity scores of week five after introducing three dimensional modeling was found to be with the variable age ($r = -.03$, $p = .436$). However, none of the correlations were found to be statistically significant. Therefore, none of the independent variables included in the analysis (age, total years of construction experience, worker classification, and frequency of looking at the three dimensional model shots) were entered into the multiple regression model.

The mean labor productivity scores of week six after introducing three dimensional modeling was 0.86 (SD = 0.103). The highest correlation with the mean labor productivity scores of week six after introducing three dimensional modeling was found to be with the variable frequency of looking at the three dimensional model shots ($r = .34$, $p = .023$). The lowest correlations with the mean labor productivity scores of week six after introducing three dimensional modeling were found to be with the variables age ($r = -.02$, $p = .450$), total years of construction experience ($r = .02$, $p = .446$), and worker classification ($r = .02$, $p = .454$). Only the variable frequency of looking at the three dimensional model shots was found to be statistically significant. Therefore, the independent variables age, total years of construction experience, and worker classification did not enter into the multiple regression model. The variable frequency of looking at the three dimensional model shots did enter into the multiple regression model.

To ensure that variables entered into the multiple regression analysis did not have excessive collinearity or that any combination of the independent variables formed a singularity, the variance inflation factor (VIF) was examined. According to Hair et al. (2006), “A common cutoff threshold is a tolerance value of .10 which corresponds to a VIF value of 10” (p.230). The variance inflation factor values for this analysis ranged from 1.000 to 1.071. Therefore, no excess multicollinearity was present in the data.

The only variable that entered the model was frequency of looking at the three dimensional model shots. This variable explained 11.5% of the variance in mean labor productivity scores of week six after introducing three dimensional modeling to industrial construction workers installing structural steel in a selected industrial facility in southeastern Louisiana. This indicates that workers who reported that they looked at the three dimensional model shots more frequently tended to have higher labor productivity scores.

Conclusions, Implications, and Recommendations

Based on the findings from the study, this researcher has determined the following conclusions, implications, and recommendations:

Conclusion One

1. The individuals in the study were typical of workers installing structural steel in an industrial facility in southeastern Louisiana.

This conclusion is based on the findings that the mean age of the individuals in the study was 35.4 years. There were no individuals under the age of 21 or over the age of 60. The largest number of subjects were in the “21-30” year age group (\underline{n} = 18 or 43.9%).

The subjects in the study were all male. It is typical and common to find construction sites having a majority male workforce. However, based on industry knowledge and experience this researcher acknowledges the increasing diversity of the female construction workforce on industrial

construction projects. It must be stated again that this study was based on a limited number of subjects involving only one work location.

The mean total years of construction experience of the individuals in the study was 12.4. The range of total years of construction experience was 1 to 35. The largest number of subjects were in the “6-10” year construction experience group ($\underline{n} = 20$ or 55.6%). Lastly, the majority of individuals were classified as “Mechanic A” ($\underline{n} = 29$ or 70.7%).

Since the research was exploratory in nature, no previous literature reviewed specifically addressed the selected personal and professional demographic characteristics used in this study. However, the conclusion that the individuals in the study were typical structural steel workers is based on this researcher’s 25 years professional experience in the industrial construction industry.

Conclusion Two

2. The majority of subjects in the study reviewed the three dimensional model shots at least occasionally.

This conclusion is based on the finding that 57.1% of the individuals looked at the three dimensional model shots either “occasionally”, “several times”, or “many times”. The reasons behind this result could include several factors. The individuals may have looked at the three dimensional model shots just out of pure curiosity with trying something new. Perhaps the workers were motivated to improve their work processes to increase productivity. Maybe the individuals had an interest in using new technology in order to get a better representation of the installation process through visualization.

This conclusion and possible reasons are supported by the literature reviewed. Campbell (2007) found that three dimensional modeling has spatial characteristics to better represent complex construction conditions. Li et al. (2008) reported that construction personnel can use the three dimensional model shots to visualize the work process before performing any tasks. Rivard et al.

(2004) found that with the aid of a three dimensional model, workers are able to visualize the completed product before it is actually built.

This researcher recommends further research regarding the motivation of construction workers to use new technology such as three dimensional modeling for visualization during the construction process. This research could provide an insight on how to implement more advanced technology during the construction phase to increase labor productivity. In addition, the impact of motivating the workers could provide two viable reasons for labor productivity improvement. The first reason for labor productivity improvement may come from a pure motivational factor the workers experience about the construction process due to the use of new technology. The second reason for labor productivity improvement may come from the motivation of each worker wanting to review the three dimensional model shots and actually visualizing the work process therefore increasing productivity.

This researcher recommends that the managers in the construction industry adapt motivational techniques for supervisors and workers to increase the frequency of reviewing the three dimensional model shots. One of the findings in the study indicated that 42.9% of the workers looked at the three dimensional model shots “very little” or “never”. There could be incentive programs established such as increasing the hourly pay rate of workers or providing bonuses to reward the workers if their labor productivity measures improved using the three dimensional model shots. Another incentive program recommended is to provide positive recognition at safety meetings to individuals if their labor productivity measures improved using the three dimensional model shots.

Conclusion Three

3. The labor productivity of subjects in the study before introducing three dimensional modeling was highly variable.

This conclusion is based on the finding that the mean labor productivity ranged from 0.45 to 1.28 during the pretest period. The mean labor productivity for week one was 1.28 and represented the highest labor productivity during the study. The mean labor productivity for week two was 0.78. The mean labor productivity for week three was 0.45 and represented the lowest labor productivity during the pretest phase of the study.

The implication of this finding is that several factors could have caused the high variation in labor productivity. One of the factors could have been material delays. It was noted by this researcher that steel was not being delivered as previously scheduled. This created work flow issues and did not allow maximum installation of steel members during certain periods. Another factor could have been delays from weather conditions. Even though the delays were tracked separately on the timesheets, there were issues with muddy work areas, not being able to access the steel during wet conditions, and the start-stop aspect of delays. Another factor could have been progress reporting issues especially during week one. Perhaps the labor hours earned was over reported that resulted in a high productivity score. The last factor discussed is the effect of working more than 40 hours during a given week (overtime). As the mean labor hours expended increased from week one to week three, the mean labor productivity for each week decreased (mean hours expended for week one = 31.3, week two = 37.5, week three = 50.7; mean labor productivity for week one = 1.28, week two = 0.78, week three = 0.45). Although not part of this particular study, the effect of working more than 40 hours during a given week could have been a factor in the high variability in mean labor productivity.

The review of related literature supports this conclusion. Adrian (2004) found that material delays, weather, and working more than 40 hours during a given week can contribute to labor productivity variability and losses.

Future research should be conducted to determine if the mean labor productivity before introducing three dimensional modeling as calculated during this study is typical of the mean labor productivity during installation of structural steel at other industrial facilities located in southeastern Louisiana. The results of the future research could solidify the findings in this study.

This researcher recommends to the managers in the construction industry to determine the impact of working more than 40 hours in a given week on industrial construction projects. Weekly labor productivity could be tracked during the initial 40 hours of work and after 40 hours of work. A cost-benefit analysis could be performed to answer these questions: Is it feasible to work greater than 40 hours in a week? Does the additional worker overtime pay and projected labor productivity losses justify working greater than 40 hours? Is overtime required to meet the current project schedule? Is overtime required to alleviate possible contractual liquidated damages for not meeting agreed upon schedule completion dates?

Conclusion Four

4. The introduction of three dimensional model shots had a significant impact on labor productivity measures.

This conclusion is based on the finding that the comparison of labor productivity before introducing three dimensional modeling with each of the three consecutive weekly measures taken after introducing three dimensional modeling yielded significant differences. There was a significant difference found during week four ($t = -6.233$, $p < .001$). In addition, there was a significant difference found during week five ($t = -13.236$, $p < .001$). However, the mean labor productivity during week four ($\underline{M} = 0.58$) was lower than the mean labor productivity during weeks one through three ($\underline{M} = 0.73$). Additionally, the mean labor productivity during week five ($\underline{M} = 0.41$) was lower than the mean labor productivity during weeks one through three ($\underline{M} = 0.75$). The reasons behind the results for weeks four and five could include several factors.

The introduction of new material such as the three dimensional model shots could have caused a disruption in the worker's normal routine of structural steel installation. Perhaps they didn't know how to fully utilize the concept of visualization that the three dimensional model shots provided. Resistance to change is another factor that could have caused a decrease in labor productivity during weeks four and five. The workers may have resisted reviewing the model shots. This factor is supported from the finding of the study that 42.9% of the workers looked at the three dimensional model shots "very little" or "never".

However, the introduction of three dimensional model shots had a significant positive impact on labor productivity measures during week six. This conclusion is supported by the findings in this study. There was a significant difference found during week six ($t = -3.517$, $p = .001$). The mean labor productivity during week six ($\bar{M} = 0.86$) was higher than the pretest mean labor productivity during weeks one through three ($\bar{M} = 0.75$).

The mean labor productivity after introducing the three dimensional model shots may have been higher if more of the workers reviewed the model shots. This is supported from the finding of the study that 42.9% of the workers looked at the three dimensional model shots "very little" or "never". In addition, if this researcher or the company's supervision stressed the importance and helpfulness of reviewing the model shots the mean labor productivity may have been higher. This is supported from the finding of the study that 42.9% of the workers perceived the helpfulness of the model shots as "a little helpful" or "not at all helpful".

This conclusion is supported by the literature reviewed. Khanzode, Fischer, and Reed (2008), Khanzode and Staub-French (2007), Akanmu, et al. (2011), McGraw Hill (2009), Gilligan and Kuntz (2007), and Campbell (2007) found that the use of three dimensional modeling can result in labor productivity improvements.

A recommendation for further research is to conduct similar studies at multiple industrial facilities during structural steel installation as well as other construction disciplines. These studies could answer the questions: Are the results the same at other work locations for steel installation? Are there labor productivity improvements as a result of utilizing three dimensional modeling for visualization purposes for other disciplines such as piping erection?

Another recommendation for further research is to conduct similar studies at construction sites in other sectors such as commercial and residential. These studies could answer the question: Are there labor productivity improvements as a result of utilizing three dimensional modeling for visualization purposes in other construction sectors?

In addition, this researcher recommends that chief executive officers of construction organizations implement the use of three dimensional modeling during the construction phase of projects to enable the workers to visualize the installation process before it occurs. This researcher is knowledgeable of the fact that every project will not have a three dimensional model available. However, for those projects that do, implementation is recommended.

The implications of this finding are vast and unlimited. By improving labor productivity, the overall cost of the project is reduced. If the project is working under a reimbursable type of contract arrangement, the owner of the facility experiences a cost savings. If the contract is a fixed or lump sum type, the contracting firm benefits from the reduction of labor costs. With the cost savings, the company may want to share the additional profits with their employees in the form of incentive or bonus pay. Over the long term if determined to be a competitive advantage, the company may be able to offer construction services at lower labor costs than competitors and increase market share strictly due to the implementation of three dimensional modeling.

By improving labor productivity, the duration of a project may be reduced. This project schedule reduction may lead to additional cost savings due to shorter durations of onsite

supervision, staff, and construction equipment. In addition, the owner may be able to utilize the completed facility sooner and advance manufacturing production goals.

Conclusion Five

5. The frequency of individuals in the study reviewing the three dimensional model shots had a significant impact on labor productivity measures.

This conclusion is based on the finding in the study that the variable frequency of looking at the three dimensional model shots was found to be a statistically significant predictor of productivity in week six. The correlation between the mean labor productivity measures of week six and the variable frequency of looking at the three dimensional model shots was moderate ($r = .34$, $p = .023$). The variable frequency of looking at the three dimensional model shots entered into the multiple regression model. This variable explained 11.5% of the variance in mean labor productivity scores of week six after introducing three dimensional modeling. The variable frequency of looking at the three dimensional model shots was found to be a significant explanatory factor of the labor productivity improvements.

The review of related literature supports this conclusion. Li et al. (2008) indicated the workers could review the model shots to visualize the work process before starting material installation. As a result, Li et al. (2008) found that potential cost savings could be realized by implementing the use of three dimensional model shots during construction activities.

This researcher recommends that future research be conducted to determine if other mechanisms to convey the three dimensional model shots have a significant impact on labor productivity measures. In lieu of 8 ½ x 11 color paper, the study could include the use of portable computer tablets to show the model shots. Perhaps future research could include the live model being available on portable computer tablets or large monitors at the work location where the workers could rotate the model in any direction and view the material components from any given

perspective. This research could answer the question: Would this increase worker motivation and result in labor productivity improvements?

The implication of this finding is that if the frequency of reviewing the three dimensional model shots on 8 ½ x 11 color paper had a significant impact on labor productivity measures then a better mechanism to convey the same information may prove to increase the frequency of reviewing the model shots therefore improving labor productivity even further. The results could prove to provide a historic, unprecedented, and positive impact for the construction industry.

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APPENDIX A: COMPANY TIMESHEET

Company xyz			TIMESHEET							
			Client: Southeastern LA Facility				Date:			
			Project: Industrial Construction							
DATE										
PROJECT COST CODE										
WORK DESCRIPTION										
TIME SHEET WORK CREW: Steel1										
Employee Information		CRAFT	M/H	M/H	M/H	M/H	M/H	M/H	M/H	TOTAL
John Doe		MA								
ID# 12345										
TOTAL HOURS										
SIGNATURE										PAGE ____ OF ____

APPENDIX B: FOREMAN'S REPORT

Progress Reporting													
Structural Steel Installation													
Foreman's Book													
Foreman <u>John Doe</u>													
Description	Item	Piece Mark	Activity No.				Progress (% Complete)						
STAGE @ SITE	W10 x 33	1573B	1600	10	20	30	40	50	60	70	80	90	100
INSTALL MEMBER & CONNECT	W10 x 33	1573B	1601	10	20	30	40	50	60	70	80	90	100
BOLT OUT/WELD	W10 x 33	1573B	1602	10	20	30	40	50	60	70	80	90	100
RATTLE	W10 x 33	1573B	1603	10	20	30	40	50	60	70	80	90	100
FINAL SELL OFF	W10 x 33	1573B	1604	10	20	30	40	50	60	70	80	90	100
STAGE @ SITE	W10 x 33	1574B	1605	10	20	30	40	50	60	70	80	90	100
INSTALL MEMBER & CONNECT	W10 x 33	1574B	1606	10	20	30	40	50	60	70	80	90	100
BOLT OUT/WELD	W10 x 33	1574B	1607	10	20	30	40	50	60	70	80	90	100
RATTLE	W10 x 33	1574B	1608	10	20	30	40	50	60	70	80	90	100
FINAL SELL OFF	W10 x 33	1574B	1609	10	20	30	40	50	60	70	80	90	100
STAGE @ SITE	W12 x 50	1575B	1610	10	20	30	40	50	60	70	80	90	100
INSTALL MEMBER & CONNECT	W12 x 50	1575B	1611	10	20	30	40	50	60	70	80	90	100
BOLT OUT/WELD	W12 x 50	1575B	1612	10	20	30	40	50	60	70	80	90	100
RATTLE	W12 x 50	1575B	1613	10	20	30	40	50	60	70	80	90	100
FINAL SELL OFF	W12 x 50	1575B	1614	10	20	30	40	50	60	70	80	90	100

APPENDIX C: POSTTEST SURVEY

We value your opinion!

Please answer the following 4 questions:

1. How often did you look at the 3D model shots (computer pictures)?

Check one:

Never _____

Very Little _____

Occasionally _____

Several Times _____

Many Times _____

2. How helpful did you find the 3D model shots?

Check one:

Not at all helpful _____

A Little helpful _____

Fairly helpful _____

Helpful _____

Very helpful _____

3. How many **Total Years** of construction experience do you have? _____

4. What is your name? _____

Thank you for answering these questions.

APPENDIX D: INSTITUTIONAL REVIEW BOARD APPROVAL

ACTION ON EXEMPTION APPROVAL REQUEST



Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/irb

TO: Gerrad Delatte
HREWD

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: July 15, 2014

RE: IRB# E8862

TITLE: The Effects of 3-Dimensional Modeling on Labor Productivity Through Enhancing Visualization of Craft Workers in the Industrial Construction Industry

New Protocol/Modification/Continuation: New Protocol

Review Date: 7/15/2014

Approved X **Disapproved** _____

Approval Date: 7/15/2014 **Approval Expiration Date:** 7/14/2017

Exemption Category/Paragraph: 2a

Signed Consent Waived?: Yes

Re-review frequency: (three years unless otherwise stated)

LSU Proposal Number (if applicable): _____

Protocol Matches Scope of Work in Grant proposal: (if applicable) _____

By: Dennis Landin, Chairman 

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. SPECIAL NOTE:

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at <http://www.lsu.edu/irb>*

APPENDIX E: INSTITUTIONAL REVIEW BOARD APPROVAL - MODIFICATION

ACTION ON EXEMPTION APPROVAL REQUEST



TO: Gerrad Delatte
HREWD

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: August 5, 2014

RE: IRB# E8862

TITLE: The Effects of 3-Dimensional Modeling on Labor Productivity Through Enhancing Visualization of Craft Workers in the Industrial Construction Industry

Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/irb

New Protocol/Modification/Continuation: Modification

Brief Modification Description: Adding post test survey

Review date: 8/5/2014

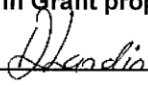
Approved X **Disapproved** _____

Approval Date: 8/5/2014 **Approval Expiration Date:** 7/14/2017

Re-review frequency: (three years unless otherwise stated)

LSU Proposal Number (if applicable): _____

Protocol Matches Scope of Work in Grant proposal: (if applicable) _____

By: Dennis Landin, Chairman 

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
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VITA

Gerrad Matthew Delatte was born and raised in southeastern Louisiana. He graduated from East Ascension High School and at the last minute decided to attend college at Louisiana State University majoring in construction. After receiving the most outstanding senior award in construction at Louisiana State University, Gerrad graduated in 1990 with a Bachelor of Science degree in Construction. After graduation, he entered the industrial construction industry. After five years of working different assignments, Gerrad started evening school at Louisiana State University while continuing to work full time to pursue a master's degree. Gerrad earned his Master of Business Administration degree in 1998.

In 2007, Gerrad began teaching industrial construction classes at Louisiana State University as an adjunct instructor. In 2010, Gerrad began his journey to pursue a doctorate. Gerrad serves on the Board of Directors of the Construction Industry Advisory Council and remains working in the industrial construction sector while teaching students about a great industry.